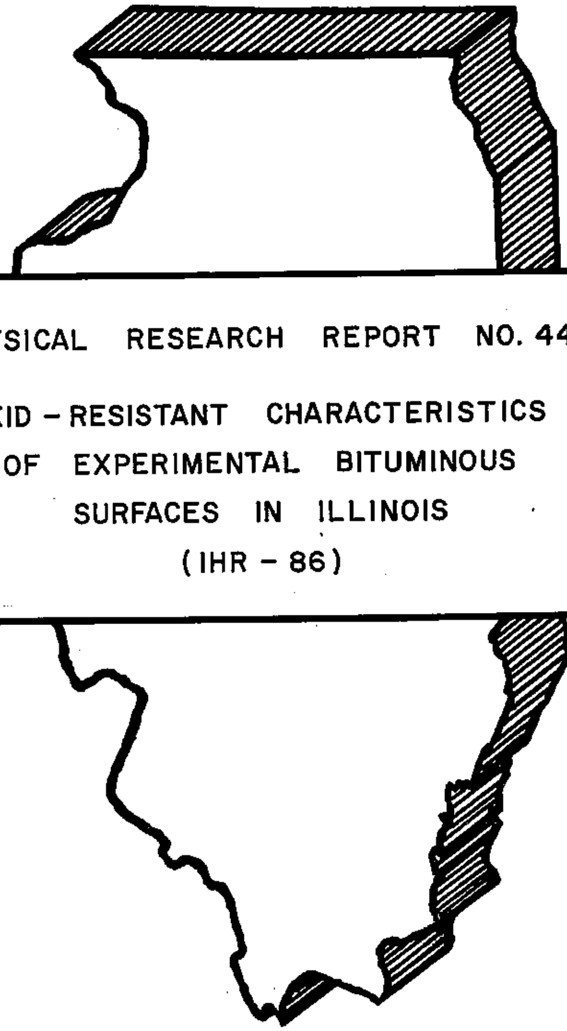
STATE OF ILLINOIS

DEPARTMENT OF TRANSPORTATION

DIVISION OF HIGHWAYS



PHYSICAL RESEARCH REPORT NO. 44

SKID - RESISTANT CHARACTERISTICS OF EXPERIMENTAL BITUMINOUS SURFACES IN ILLINOIS

(IHR - 86)

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State of Illinois
DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

SKID-RESISTANT CHARACTERISTICS OF EXPERIMENTAL BITUMINOUS SURFACES IN ILLINOIS

By

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Interim Report
IHR-86
Skid Resistance of Pavement Surfaces

A Research Project Conducted by
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16. Abstract

Skid resistance was among several factors used to evaluate bituminous mixtures, which were placed as experimental surfaces at 17 sites in Illinois. Skid tests indicated that surface texture as represented by changes in macroroughness and microroughness substantially controls the skid resistance of a surface. For the same kind of aggregate, dense-graded mixes that have a 1/2-inch top size aggregate provided higher skid numbers than either sand asphalt or binder course mixes. On the other hand, when aggregate gradation was held constant, air-cooled slag or Synopal, which have excellent microroughness, gave higher skid numbers than limestone or other aggregates that have less microroughness. Moreover, adding rubber to bituminous mixes or substituting stone sand for natural sand in a regular Class I surface course mix produced little, if any change in skid resistance. Bituminous surfaces designed for optimum macroroughness and microroughness should continually give adequate skid numbers regardless of wear, and bituminous mixes that produce a smooth surface texture obviously should be avoided.

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CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

TABLES

SKID-RESISTANT CHARACTERISTICS OF EXPERIMENTAL BITUMINOUS SURFACES IN ILLINOIS

SUMMARY

A number of different fine dense-graded bituminous concrete mixtures were placed as experimental pavement overlays between 1965 and 1971 at 17 sites in Illinois. Because bituminous overlays are used frequently as a method of eliminating slippery pavements that contribute to skidding accidents, skid resistance was a prime factor used to assess their surface behavior. The knowledge gained from these tests was needed by design and by traffic engineers for improving and maintaining skid resistance of pavements, especially at intersections and at curves where stopping and turning maneuvers are critical.

Comparative tests were made at each site with a skid-test trailer, and tests were made usually twice a year. Using skid numbers derived from these tests, the skid resistance of each test section was plotted as a function of time and as a function of accumulated axles that pass over a test section. As trends developed, it became evident which mixes were acceptable, marginal, or unacceptable as skid-resistant surfaces and why each mix seemed to fit into a particular category.

Of the bituminous mixtures tested, surface texture as represented by both macroroughness and microroughness appeared to be the most significant factor that influenced skid resistance. When air-cooled slag or Synopal, both having excellent microroughness, were substituted for or blended with limestone that has little microroughness, they improved the skid resistance of that bituminous surface. Moreover, results of tests suggested that blends containing at least 50 percent by volume of the coarse aggregate having the better microroughness were more effective.

Regardless of the kind of aggregate used, there appears to be an optimum coarse aggregate gradation that will provide the highest skid number. For example, Illinois' Bituminous Concrete Surface Course (Class I) that has 1/2-inch top in size aggregate and retains approximately 60 percent of the aggregate above the No. 10 sieve, provided higher skid numbers than either sand asphalt or binder course mixes. In addition to gradation, blends comprised of hard and soft aggregates which wear differently maintained good macroroughness throughout the life of the surface.

Because coarse rather than fine aggregates control skid resistance of bituminous concrete surfaces, comparative tests confirmed that substituting stone sand for natural sand in a regular Class I surface course mix made no significant change in skid resistance.

Furthermore, rubber additives, which enhance the structural behavior of thin bituminous overlays by changing the physical properties of the asphalt binder, have no significant effect on skid resistance of the surfaces examined.

Of the surface and binder course mixtures tested, Synopal (50 percent) and slag were rated as acceptable (SN above 36), and crushed gravel and Synopal (25 percent) were rated as marginal (SN 30-36). Although surface course mixtures are preferred, sand asphalt surfaces such as Gripstop, Tapisable, slag sand, and coarse natural sand seals also were rated acceptable, while trap rock, wet-bottom boiler slag, and stone sand (limestone) seals were rated marginal. After reviewing the bituminous surfaces included in this study, it seems apparent that bituminous surfaces designed for optimum macroroughness and microroughness should provide acceptable skid numbers regardless of wear, and bituminous mixes that produce a smooth texture, obviously, should be avoided.

Seasonal variations up to 10 skid numbers occurred at sites where hard aggregates, above 5 on Mohs' scale, prevailed. For the same number of axle applications, similar mixes exposed to rural and to urban expressway traffic showed the latter to have a skid resistance as much as 4 skid numbers lower. This lower number resulted primarily from observed contamination continually building up on the surface and from a greater volume of heavy trucks on urban expressways. On the other hand, wear was more predominant on surfaces comprised of soft aggregates, 3 to 4 Mohs' scale, when exposed to high traffic volumes.

Skid number-speed gradients as determined from the test sites at Troy ranged from 0.6 to 0.8 which are representative of the fine-textured surfaces according to Kummer and Meyer. 3/ They reported gradients of 0.2 for coarse-textured surfaces to 0.8 for fine-textured surfaces.

INTRODUCTION

Since the early 1920's, vehicle speed and vehicle registration have risen continually and have added to a national concern over an ever-increasing number of skidding accidents. Although the skid resistance of dry pavement usually is excellent, the skid resistance of a wet pavement is reduced on the average by one half of its dry value. This frictional loss, which contributes to skidding accidents, is more critical at intersections and at curves where stopping and turning maneuvers occur than along a straight section of highway. In some cases skidding can be reduced by increasing only the skid resistance of the surface, but in other cases, changes in roadway alignment, in cross-section, in signs, and in pavement markings are necessary. Illinois, like many other states, shares this concern for slippery pavements and undertook in 1967 a research study of pavement skid resistance in cooperation with the Federal Highway Administration.

The objectives of this research are (1) to develop new equipment or improve existing equipment for determining the skid resistance of highway surfaces, (2) to determine the skid resistance of highway pavements, intersections, and interchanges, (3) to study the polishing characteristics of aggregates used in pavement surfaces, (4) to develop an economical means of increasing the skid resistance of slippery pavements, and (5) to assemble a more positive body of knowledge concerning skid resistance for incorporation in highway design and safety policies.

The study has been divided into five phases corresponding to each objective of the research. Phase 1, which deals with development of equipment, has been completed and is described in two reports. The skid-test system has been described by Kubiak in an interim report entitled "Selection and Design of a Skid Tester." 1/

A second interim report entitled "Modification and Calibration of the Illinois Skid-Test System" 2/ by Kubiak and others was published, completing the work in Phase 1. Field work for both Phases 2 and 3 has been completed, and analysis of these data is under way.

This interim report describes 17 experimental bituminous surfaces that have been tested as a part of Phase 4, and presents the changes in skid resistance that have occurred to these surfaces with respect to time and wear. Site selection, test equipment, and test procedures are discussed briefly. Finally, each material is rated for its acceptability as a skid-resistant surface.

Phase 4 involved selecting and testing pavements where improvements for skid resistance have been made to existing surfaces. The experimental surfaces discussed here are grouped as either multiple- or single-test sections. Multiple-test sections are where two or more experimental mixtures have been placed at the same geographical location and are exposed to the same traffic and climate. Single-test sections, on the other hand, are where one experimental mixture has been placed at one geographical location so that each experimental surface is exposed to a different traffic and climate.

Because new experimental mixtures are placed each year, the testing in Phase 4 is continuing in nature. Nevertheless, sufficient skid tests have been accumulated now to indicate which experimental mixtures show promise as skid-resistant surfaces. Of the several different aggregates that have been tried, none have exhibited outstandingly superior skid-resistant qualities, but surfaces containing air-cooled blast furnace slag, Synopal, Tapisable, natural sand and Gripstop have performed satisfactorily and are considered acceptable for upgrading slippery surfaces.

STUDY DETAILS

In Illinois, a number of experimental bituminous surfaces, which have been placed as either product development or safety improvement projects have been and still are being tested for skid resistance with the Department's two-wheel skid-test trailer. This section describes site selection, test equipment and procedures, and analysis procedures used to evaluate these experimental mixtures.

Site Selection

Over the years, the Department of Transportation has taken advantage of new products that appear beneficial to highway construction and maintenance. Several proprietary mixtures, additives, and manufactured aggregates that are being tested include skid resistance as one of several parameters that are being evaluated. In some cases, several experimental mixtures are placed at one site along a roadway where improving skid resistance of the existing surfaces was not an objective. At other locations, experimental mixtures that substantially improve skid resistance are being sought to reduce skidding accidents at a particular site.

Experimental bituminous surfaces have been placed as part of two safety improvement projects aimed at reducing accidents on wet pavement surfaces throughout the state. One project provided for installation and investigation of various skid-resistant materials. In June 1970, this project was discontinued after 16 sites had been improved.

The other project, from which experimental sites were obtained, was the "State of Illinois Spot Safety Improvement Program" which was directed toward reducing accidents at known high-accident locations. In this program, the improvement of skid resistance was only one of several types of improvements that could be financed with safety funds. At locations where a number of skidding accidents had occurred on wet surfaces, experimental bituminous mixtures were placed over the existing surfaces to reduce the possibility of skidding. Results of skid-test measurements on these surfaces are presented later in this report.

Thus, product development and safety improvement projects, which span the State, have provided numerous sites from which changes in skid resistance of experimental surfaces can be evaluated.

Test Equipment and Procedure

Skid tests were made with a two-wheel skid-test trailer developed by Illinois for measuring pavement skid resistance. The skid trailer, which has leaf springs, electric brakes, and a brush water applicator, is capable of making either single- or double-wheel lockups.

In general, all skid tests that were made on experimental surfaces were made in accordance with ASTM Designation: E 274-70. Except for one site where a skid resistance speed-gradient was determined at 30, 40, and 50 mph, all other tests were made at 40 mph. During each test, water was applied to the dry pavement in front of the test tire just prior to and during the 3-second brake lockup.

The number of tests made in each lane varied according to the length of the site, but the minimum number of tests per lane was never less than three. Two-wheel lockups were made on surfaces relatively short in length to obtain an adequate sample, whereas sites that were one or more miles long were tested with at least six single-wheel lockups. The skid resistance resulting from testing these surfaces is expressed in terms of a skid number which is defined as the friction coefficient of a tire sliding on wet pavement times 100.

Method of Evaluation

The three principal factors that contribute to pavement slipperiness according to Kummer and Meyer 3/ are: (1) amount of water at the tire-pavement contact area, (2) pavement wear and aggregate polish, and (3) vehicle speed. Assuming the amount of water placed in front of the test tire and the vehicle speed are held constant, changes in skid number from one test to another test can be attributed primarily to pavement wear and aggregate polish.

The chief factor contributing to pavement wear and aggregate polish is the number of vehicle axles that pass over the pavement surface. In general, as the number of axle passes accumulate, the skid resistance of the surface decreases. To a lesser degree, the load on the axle influences the skid resistance of the pavement.

A special study conducted during the AASHO Road Test suggests that heavy trucks reduce skid resistance of a surface more than light (2000-lb axle) trucks. Also the study showed that, for the same wheel loads, tandem axles were found to reduce skid resistance more than single axles. 4/ Although wheel load apparently affects skid resistance, no procedure for determining load effects has been developed. Consequently, a factor that takes into account weight was not used in computing the number of axle applications that passed over a test section.

Skid resistance as a function of time and as a function of accumulated axles has been examined for all test sections. Ideally, comparisons of skid resistance for different surfaces should be made under the same traffic and environment. Yet, almost all of the experimental test sections contained in this study are at different geographical locations where they are exposed to different traffic and climate. By using the number of axle applications as a common denominator, a comparison of skid numbers for each experimental mixture can be made.

Recognizing that the skid resistance of a surface fluctuates, a three-level adjective rating was established as a guide in rating the experimental mixtures. Because no standards have been adopted as yet for skid resistance, the ratings were based partly on tentative recommendations in National Cooperative Highway Research Program Report 37, and partly on our own experience. These ratings and corresponding skid-number ranges are as follows:

Rating	Skid Number
Acceptable	Above 36
Marginal	30 - 36
Unacceptable	Below 30

An acceptable rating assumes that the skid resistance of that bituminous mixture should satisfy normal frictional needs of traffic and should be considered for improving the skid resistance of a slippery surface. On the other hand, bituminous mixtures having a marginal rating may satisfy frictional demands in urban areas and at locations where operating speeds are less than 35 mph. When a bituminous mixture receives an unacceptable rating, obviously it should not be used to improve the skid resistance of a surface.

RESULTS - MULTIPLE TEST SECTIONS

Multiple test section experiments, which comprise two or more experimental mixtures placed at one site for comparative purposes, have been placed in Chicago, near Pontiac, and near Troy. Included in the testing at each site was a comparison of the skid resistance. A description of each experiment is presented here and is followed by a discussion of skid-test results.

Synopal, Limestone - Pontiac

Synopal, a synthetic aggregate, has been observed as an experimental paving material in Illinois since August 1965 to evaluate its effectiveness in improving skid resistance and night visibility of bituminous pavements. Synopal, a proprietary aggregate made by Synopal Limited, Thisted, Denmark, is a white mineral aggregate produced by melting sand, chalk or limestone, and dolomite, and cooling the molten mass to a granular state, and reheating to a temperature close to the melting point. Individual particles are irregularly cubic in shape, have a crushing strength 40 percent higher than granite, and have a Mohs' hardness of 7.5 (quartz is 7). The aggregate when purchased for this experiment cost $45 per ton delivered to the jobsite.

Synopal aggregate was included in a bituminous resurfacing contract on US 66, a four-lane divided highway, south of Pontiac in Livingston County. The test site begins at the junction of Illinois 116 with US 66, and extends 4 miles in the southbound roadway. The first of three test sections, which is 1 mile long, is a Class I bituminous concrete surface with Synopal replacing 25 percent by volume of the limestone coarse aggregate. The second test section, 1 mile long, is a regular Class I bituminous concrete, and separates the two Synopal test sections. The last test section, 2 miles long, is a Class I bituminous concrete surface with Synopal replacing 50 percent by volume of the limestone coarse aggregate. Synopal replaced limestone on a volume instead of a weight basis because of the wide difference in their specific gravities.

The materials and the construction procedures used to place the new surface met the requirements of Section 46, Bituminous Concrete Surface Courses, Fine Dense-Graded Aggregate, Class I, of the Standard Specifications for Road and Bridge Construction adopted January 2, 1958. The composition of the three mixtures is shown in Table 1. As indicated by the sieve analysis, the gradation of Synopal is uniform in size. Also, the asphalt content requirement increased as the amount of Synopal used increased.

TABLE 1

TYPICAL EXTRACTION TEST RESULTS OF BITUMINOUS CONCRETE MIXTURES WITH SYNOPAL AT PONTIAC
(Sampled Behind Paver)

Sieve Size		Percent Retained (by weight)				
		Control	25% Synopal		50% Synopal	
Passing	Retained	Limestone	Synopal	Limestone	Synopal	Limestone
1/2 inch	No. 4	40.2) 58.1	12.0 +	30.7) 61.7	23.3 +	20.6) 58.7
No. 4	No. 10	17.9)	1.6 +	17.4)	3.5 +	11.3)
No. 10	No. 40	19.0)		15.9)		15.6)
No. 40	No. 80	7.4) 32.6		6.0) 27.5		7.1) 29.6
No. 80	No. 200	6.2)		5.6)		6.9)
No. 200	-	4.7		5.6		5.8
	Bitumen	4.6		5.2		5.9

A Blaw-Knox PF-180 paver with electronic leveling controls actuated by a 20-foot multi-shoe ski riding over the completed binder course placed the surface course. Immediately following the paver, two three-wheeled rollers and a pneumatic-tired roller compacted the surface. The contractor encountered no difficulties during construction.

In 1971, the average daily traffic volume at the test site was 14,000 which was equally divided between both directions of travel. The total volume consisted of 10,700 passenger cars, 1,050 single unit trucks and 2,250 multi-unit trucks. As of June 1971, 26.5 million axle passes have accumulated in the traffic lane as compared to 7.5 million axle passes accumulated in the passing lane.

Skid tests that were made in July and November 1969, July 1970, and June and November 1971 are plotted against time in Figure 1 and against accumulated axle passes in Figure 2 for both traffic and passing lanes of the southbound roadway. Skid tests for the traffic lane were not obtained in November 1971 because of a malfunction in the recorder.

In all tests, the Class I mixture containing 50 percent Synopal coarse aggregate had the highest skid numbers (37-42 in the traffic lane) followed by the Class I mixture containing 25 percent Synopal and the control Class I mixture (0 percent Synopal). Moreover, the skid resistance of the traffic lane which carries 90 percent of the vehicles, tested 6 to 12 skid numbers lower than the more lightly traveled passing lane. Although the effect of surface wear on skid resistance is obvious in Figures 1 and 2, the effect of seasonal variations also can be seen.

After 6 years service and over 26.5 million axle applications, skid tests for this experiment suggest that blending equal parts of Synopal and limestone coarse aggregates in a Class I bituminous concrete surface raises the skid resistance

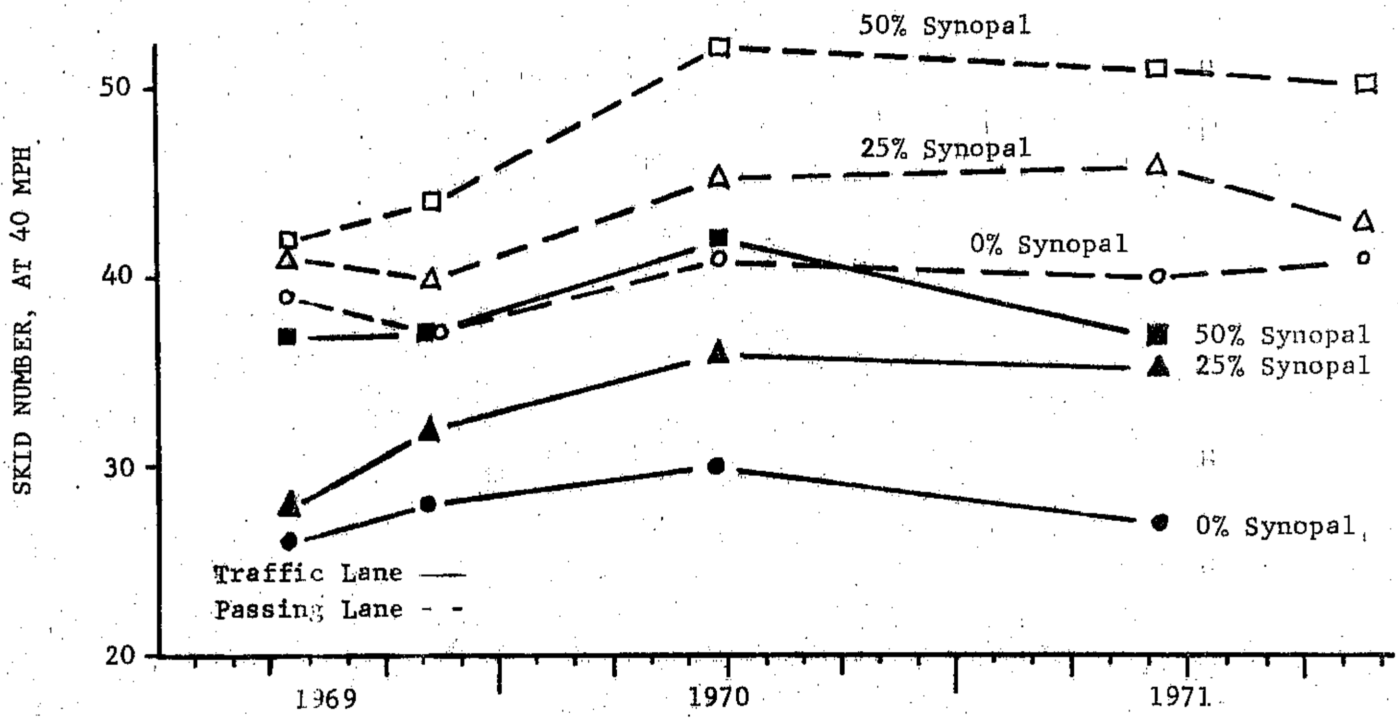


Figure 1. Graph showing influence of Synopal on skid number with time on US 66 at Pontiac.

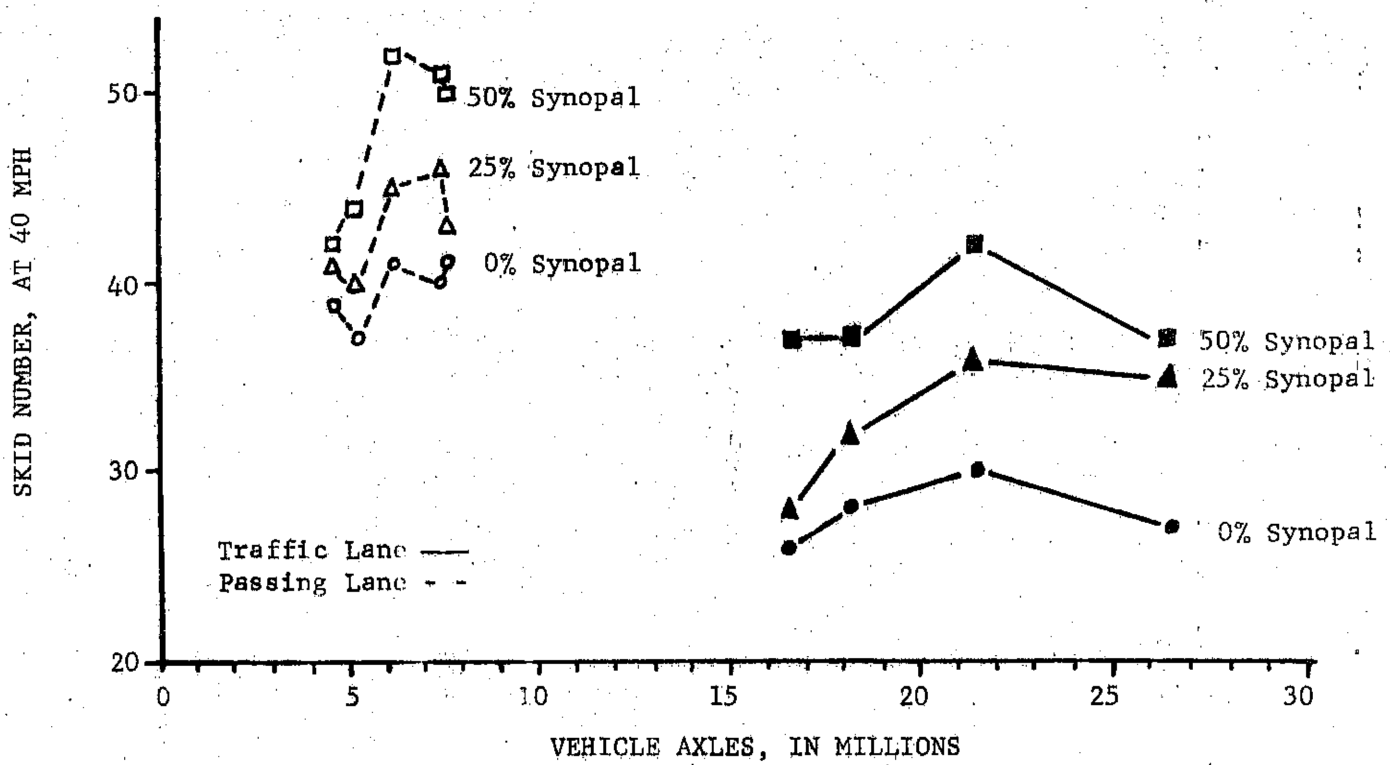


Figure 2. Graph showing influence of accumulated axle passes on skid number for Synopal on US 66 at Pontiac.

of that surface 10 to 12 skid numbers above the control Class I surface containing crushed dolomitic limestone aggregate.

On the basis of skid tests, an adjective rating for the experimental mixture containing 50 percent Synopal is acceptable, while the mixture containing 25 percent Synopal is marginal as skid-resistant surface.

Synopal, Asbestos, Limestone, Stone Sand - Chicago

Skid resistance was among four parameters that were measured as a part of a research project to evaluate the behavior of bituminous concrete overlays placed over a continuously reinforced concrete (CRC) pavement. The test site, which was 6 miles south of Chicago's Loop between 51st and 57th Streets, was in the collector-distributor lanes of the Dan Ryan Expressway. At this location in 1971, 200,000 vehicles traveled daily over four express and two collector-distributor lanes in each direction of the depressed expressway. Of this total volume, each collector-distributor lane carried 20,000 vehicles per day, of which 12,000, or 60 percent, were passenger cars and 8,000, or 40 percent, were divided equally between single- and multiple-unit trucks. Although a detailed account of this study, which lasted 21 months, will be given in another report entitled "Experimental Resurfacing of the Dan Ryan Expressway," information relating only to skid tests is presented here.

Bituminous Concrete, Binder and Surface Courses, Class I, conforming to Section 406 of the Standard Specifications for Road and Bridge Construction, and three modified Class I mixtures conforming to the Special Provisions, were placed as a 2-inch-thick surface course by conventional asphalt paving equipment in the northbound local lanes during the fall of 1969. The regular Class I mixture contained crushed dolomitic limestone as the principal aggregate. The three modified mixtures were (1) a Class I mix using dolomitic limestone sand in place of a natural sand, (2) a Class I mix containing equal parts (by volume) of dolomitic limestone and synthetic Synopal coarse aggregates, and (3) a Class I mix having an asbestos fiber additive. Typical gradations of the coarse aggregate used in each mix are listed in Table 2. The tabulation shows that the gradation of coarse aggregates in the mix containing stone sand is identical with that of the regular mix, but that the gradation of mix containing asbestos is finer than the gradation of regular mix. Synopal is a uniformly sized aggregate with 99 percent of it passing the 3/8-inch sieve and with 97.6 percent of it retained on the No. 4 sieve.

Mixing formulas for the regular and three modified Class I mixtures are shown in Table 3. When the gradations are compared, it is evident that the gradation of the stone sand mixture is the same as the regular mixture and the asbestos mixture is finer than the regular mixture. Although the Synopal gradation appears coarser than the regular Class I gradation, the lighter weight Synopal accounts for this difference.

Initially, skid tests were made in November 1969 with followup testing in May and November 1970 and again in May 1971. Because traffic volumes and skid numbers between lanes were similar, all skid numbers within a test section were averaged and plotted against accumulated axle applications in Figure 3.

It will be noted in Figure 3 that the skid resistance of all surfaces dropped from 8 to 13 skid numbers after passage of 10 million axles. Except for the Synopal mixture, which began an upward trend after 19 million axles, the skid numbers of the other mixtures continued to decline, but at a slower rate, for the remainder of the study.

TABLE 2.

TYPICAL GRADATIONS OF COARSE AGGREGATE - DAN RYAN EXPRESSWAY

Sieve Size	Percent Passing (by weight)				
	Class I Mix	Stone-Sand Mix	Asbestos Mix	Synopal Mix	
				Synopal	Limestone
1/2 in.	100	100		99.0	-
3/8 in.	99.7	99.7	100	99.0	96.7
No. 4	31.8	31.8	75.7	2.4	31.8
No. 10	-	-	14.1	2.0	-
No. 16	5.4	5.4	-	-	5.4
No. 40	-	-	5.5	-	-
No. 50	-	-	-	-	-
No. 80	-	-	4.5	-	-

TABLE 3.

MIXING FORMULAS FOR BITUMINOUS CONCRETE MIXTURES - DAN RYÁN EXPRESSWAY

Sieve Size		Percent Retained (by weight)			
Passing	Retained	Class I Mix	Sand-Stone Mix	Asbestos Mix	Synopal Mix
1/2 in.	No. 4	38.3) 59.6	38.3) 59.6	12.1) 47.1	48.2) 60.8
No. 4	No. 10	21.3)	21.3)	35.0)	12.6)
No. 10	No. 40	15.1)	15.1)	19.3)	12.1)
No. 40	No. 80	8.7) 29.8	8.7) 29.8	11.6) 37.8	10.6) 28.4
No. 80	No.200	6.0)	6.0)	6.9)	5.7)
No.200		5.2	5.2	4.7	5.3
Bitumen	(AC 85-100)	5.4	5.4	8.0	5.5
Asbestos		-	-	2.4	-

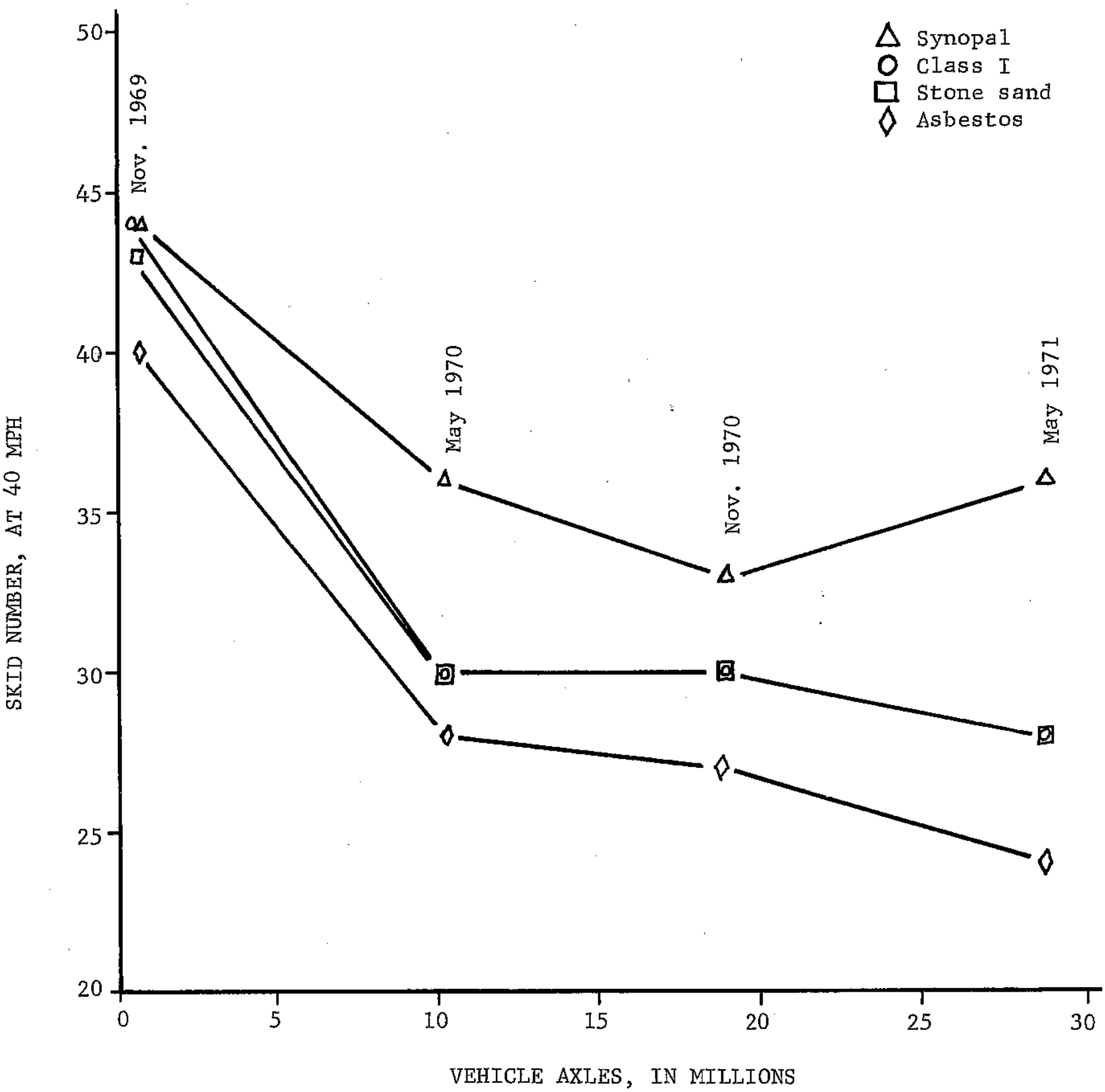


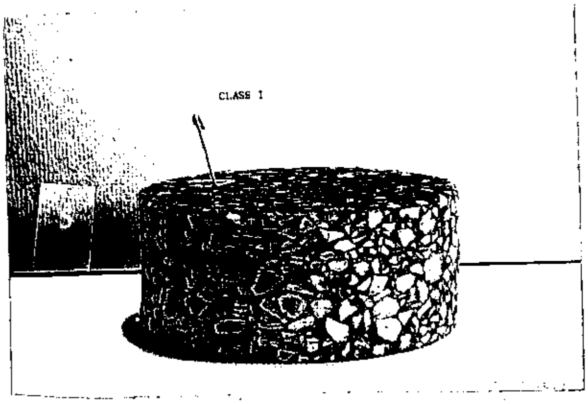
Figure 3. Graph of skid number versus accumulated axles for experimental mixtures on the Dan Ryan Expressway in Chicago.

When the regular Class I mix is used as a reference, blending equal parts of Synopal and of limestone coarse aggregate raised the skid resistance from 3 to 8 skid numbers; substituting stone sand for natural sand had no effect on skid resistance; but adding asbestos fiber which increased the asphalt content, and using a finer coarse aggregate gradation lowered skid resistance from 2 to 4 skid numbers.

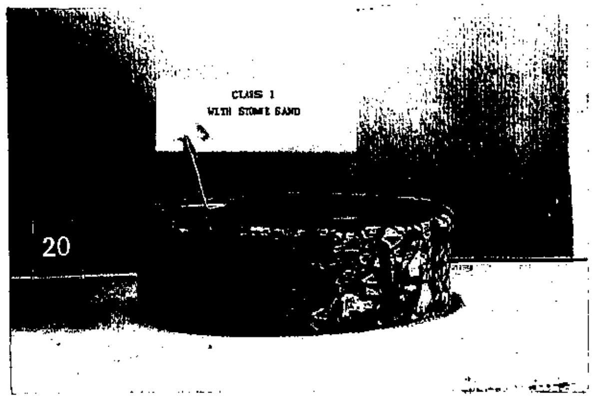
The reason that the surface containing Synopal is from 6 to 12 skid numbers higher than the surface containing asbestos fiber can be explained partly by a difference in surface texture. Cores that were taken from a wheelpath in each test section and that are shown in the photograph in Figure 4 help illustrate the difference in texture among these mixtures. For example, hard gritty Synopal aggregates (7.5 on Mohs' scale) can be seen protruding above the softer worn limestone aggregates (3-4.5 on Mohs' scale) in the Synopal surface. Consequently, added large-scale macroroughness and small-scale microroughness from the Synopal has raised the skid number of that Class I surface.

The rounded coarse texture of both the regular and the stone sand mixtures are almost identical. In fact, the skid numbers of both surfaces are nearly the same and are lower than the skid number of the Synopal mix. As previously mentioned, substituting stone sand for natural sand in a mixture had no effect on skid resistance. This observation that coarse rather than fine aggregate controls skid resistance of a mixture agrees with findings by Burnell and others. 5/

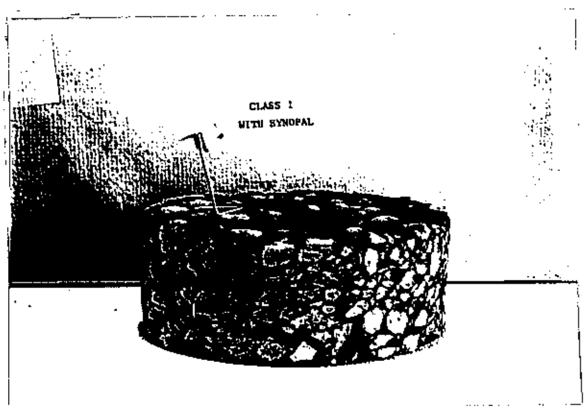
On the other hand, the finer gradation of limestone aggregate combined with asbestos and about 2 percent more asphalt produced a rounded fine-textured surface that was 2 to 4 skid numbers below the control Class I mix. Furthermore, this relatively smooth surface definitely falls in the unacceptable range (SN below 30).



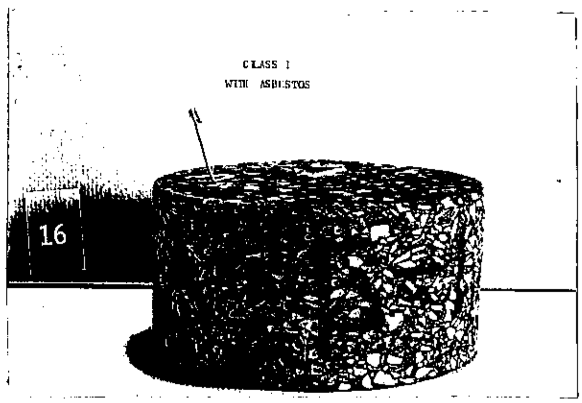
Class I



Class I with stone sand



Class I with Synopal



Class I with asbestos

Figure 4. Photograph of cores showing texture of experimental surfaces on Dan Ryan Expressway in Chicago.

In summary, this experiment illustrates that changing both macroroughness and microroughness of a bituminous surface affects skid resistance. Increasing large scale macroroughness improves water drainage while increasing small scale microroughness improves friction. Improving either one or the other or both of these textural qualities enhances the skid resistance of a surface. Blending equal parts of Synopal and limestone coarse aggregates in the dense-graded bituminous mixture, definitely improved the skid resistance of the mix over a Class I mix containing only limestone aggregate.

The skid numbers for these three experimental mixtures indicate that the Synopal mix had a marginal adjective rating while both the asbestos and the stone sand mixtures had unacceptable adjective ratings.

Slag-Limestone - Troy

When US 40 east of Troy in Madison County was resurfaced in 1971, eight experimental test sections were included in 9 miles of the 16-mile resurfacing contract. This experiment was designed to evaluate the skid resistance of both air-cooled blast furnace slag and limestone surfaces. Of the eight test surfaces, three were standard Class I Bituminous Concrete Surface Courses, three were Class I Bituminous Concrete Binder Courses used as surfaces, and two were Class I Bituminous Concrete Surface Courses modified as a sand asphalt mixture all conforming to Section 406, Bituminous Concrete Binder and Surface Courses, Class I, of the Standard Specifications for Road and Bridge Construction and to applicable special provisions of the contract. Individual test sections, which varied from 0.75 to 1.50 miles long, contained limestone, air-cooled blast furnace slag or a limestone-slag blend as coarse aggregate, natural sand as fine aggregate, and limestone dust as mineral filler.

The suggested mixing formula for each mixture is shown in Table 4, and a comparison of the hot-bin analysis for each mixture is given in Table 5. Each mixture as listed in those tables is grouped according to surface course, binder course, and sand course mixtures. A limestone, a slag and a limestone-slag blend mix were in the surface and the binder course categories, but only a limestone and a slag mix were in the sand course category.

These mixtures were machine-laid by conventional methods in May 1971. The thickness of the courses varied from 3/4 to 1 1/2 inches. At the experimental site, Route US 40 is a two-lane pavement with an ADT of 2,200 vehicles.

Skid tests on the eight surfaces were made in July and November 1971 and again in June 1972. At the time of the 1972 tests, approximately 2 million vehicle axles had passed over the test surfaces. Since these tests were made rather early in the life of the pavement, a speed gradient rather than a wear curve was chosen as a means of evaluating their relative performance. To establish a skid number-speed gradient curve for each mix, skid tests were made at 30, 40, and 50 mph.

The results of these tests are shown in Figures 5 and 6. Figure 5 presents skid number-speed gradient curves according to the type of aggregate used in each mix, while Figure 6 illustrates skid number-speed gradient curves according to the size of coarse aggregate used in a mixture.

Analysis of the skid number-speed gradient curves for these eight mixtures after 2 million axle applications indicates the following:

1. Bituminous surfaces containing slag aggregate generally have a skid resistance from 5 to 16 skid numbers higher than bituminous surfaces containing limestone aggregate regardless of the size of coarse aggregate used in a mixture (Figure 5).

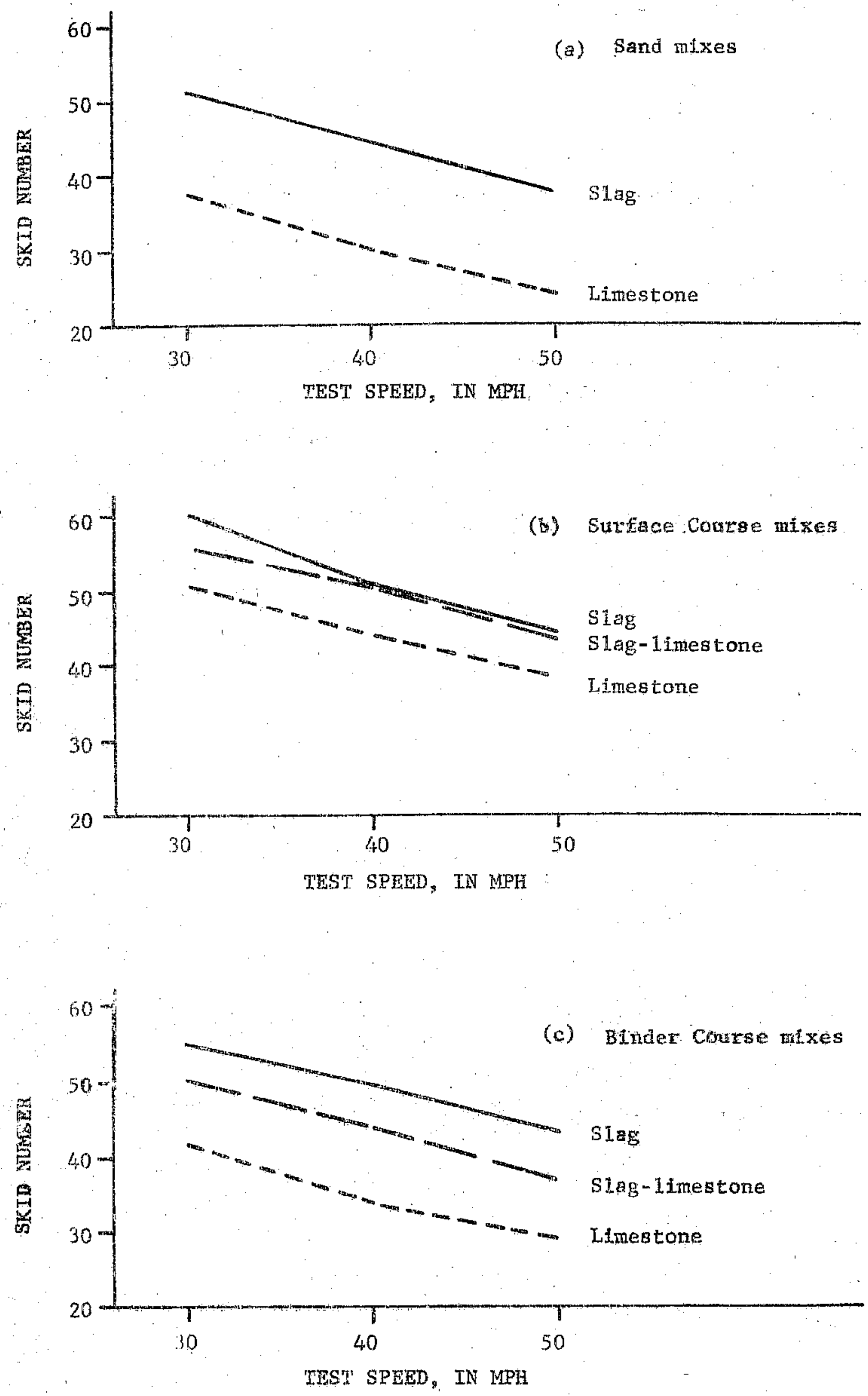


Figure 5. Comparison of skid number-speed gradient by type of aggregate.

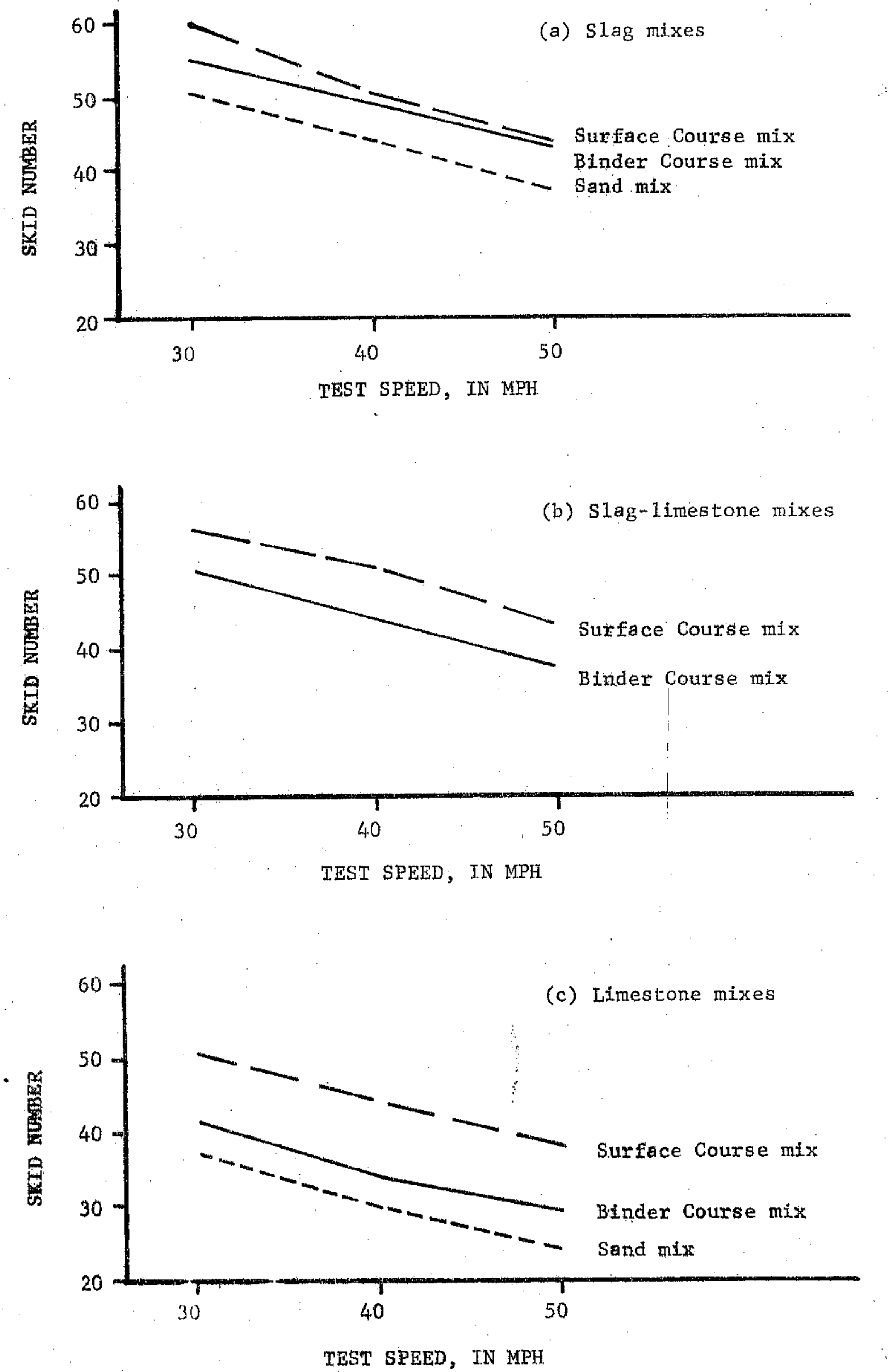


Figure 6. Comparison of skid number-speed gradient by size of coarse aggregate.

2. Comparative tests indicate that blending air-cooled blast furnace slag (6-7 Mohs' scale) with limestone (3-4 on Mohs' scale) aggregate improves the skid resistance of a bituminous mixture (Figure 5).

3. Regardless of aggregate type, surface course mixes gave higher skid numbers than either sand or binder course mixes (Figure 6). Apparently, optimum gradation occurred when approximately 60 percent of the aggregate was well graded between the 1/2-inch and the No. 10 sieves (Table 5).

4. No significant difference was noted in the skid number-speed gradient (30-50 mph) among different coarse aggregate gradations or aggregate types. However, the skid-number-speed gradients, which ranged from 0.60 to 0.80, tend to represent fine-textured rather than coarse-textured surfaces.

When planning this study, it was believed that varying the amount and size of coarse aggregate retained above the No. 10 sieve in a fine dense-graded bituminous mixture would cause a change in macroroughness or macrotexture of the surface.

To evaluate texture depth among the eight text surfaces, measurements were made by the putty impression method which was originally developed as a means of making texture correction factors for nuclear density measurements. 6/ Four representative impressions were made in the outer wheelpath of each test section. The average textural depth for all test sections in Table 6 was .033 inch, while the average texture depth for individual test sections range from a low of .024 inch for the slag-sand mix to a high of .040 inch for the limestone-slag blend. Apparently, such values are typical of dense-graded bituminous concrete because they are similar to values reported by Gallaway and by Rose for hot-mix asphalt concrete. 6/ 7/

TABLE 6

MACROROUGHNESS VALUES AT TROY

Type Aggregate	Average Texture Depth (Putty Impression) in inches		
	Sand Mix	Surface Course Mix	Binder Course Mix
Limestone	0.035	0.028	0.032
Limestone-Slag	-	0.040	0.037
Slag	0.024	0.032	0.033

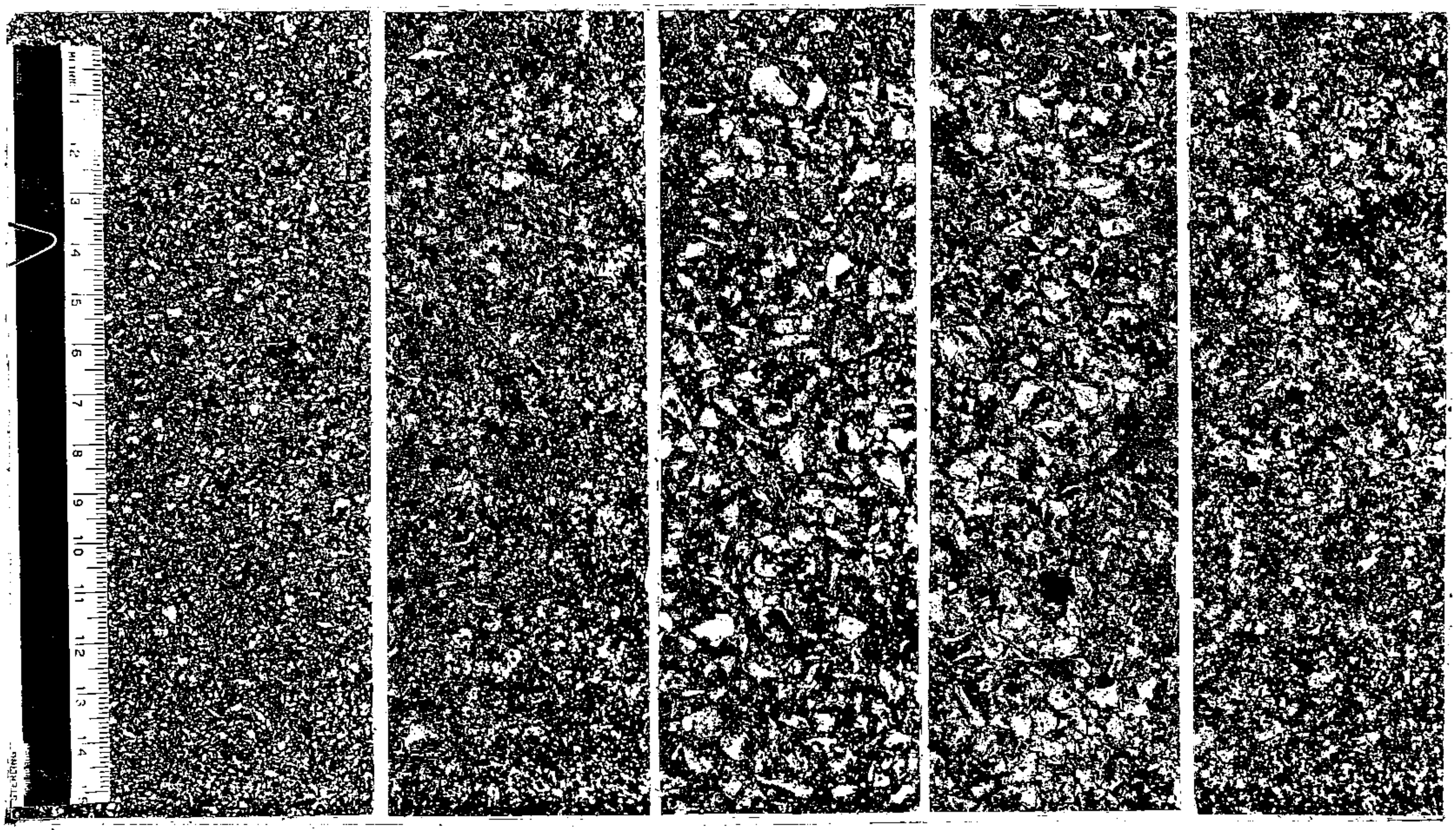
Although the size of coarse aggregate was adjusted above and below the size of coarse aggregate usually found in a Standard Class I Surface Course, texture depth still showed no significant change as was originally expected. However, blending limestone with air-cooled blast furnace slag gave slightly more texture than using either limestone or slag alone in a bituminous mixture.

Nevertheless, skid number-speed gradient curves suggest that aggregate gradation influences skid resistance, yet when skid number-speed gradients were obtained and when texture measurements were made by the putty impression method, no significant trend in macroroughness was noted among the sand asphalt, surface, and binder courses.

Although both Mix 4 and Mix 5 are considered sand mixtures, the slag-sand gradation, Mix 5, contains 39.9 percent coarse aggregate retained above the No. 10 sieve as compared to 3.2 percent coarse aggregate for the limestone-stone sand, Mix 4. This difference may account, in part, for slag sand having a higher skid resistance than the stone sand mix.

Figures 7 and 8, which are photographs of the eight surfaces, illustrate the differences in gradation among mixtures. These photographs, which were taken at the time of the second series of tests, show the wheelpath portion of the pavement from the same camera elevation above the surface. The photographs verify the difference in gradation between slag sand (Mix 5) and stone sand (Mix 4), which are both considered fine-textured mixtures. As can be seen in Figure 7, the limestone has a much tighter surface and correspondingly has a lower skid number.

The vesicular nature of the slag aggregate, which is illustrated in the photographs of the surface course and binder course mixes, enchances the



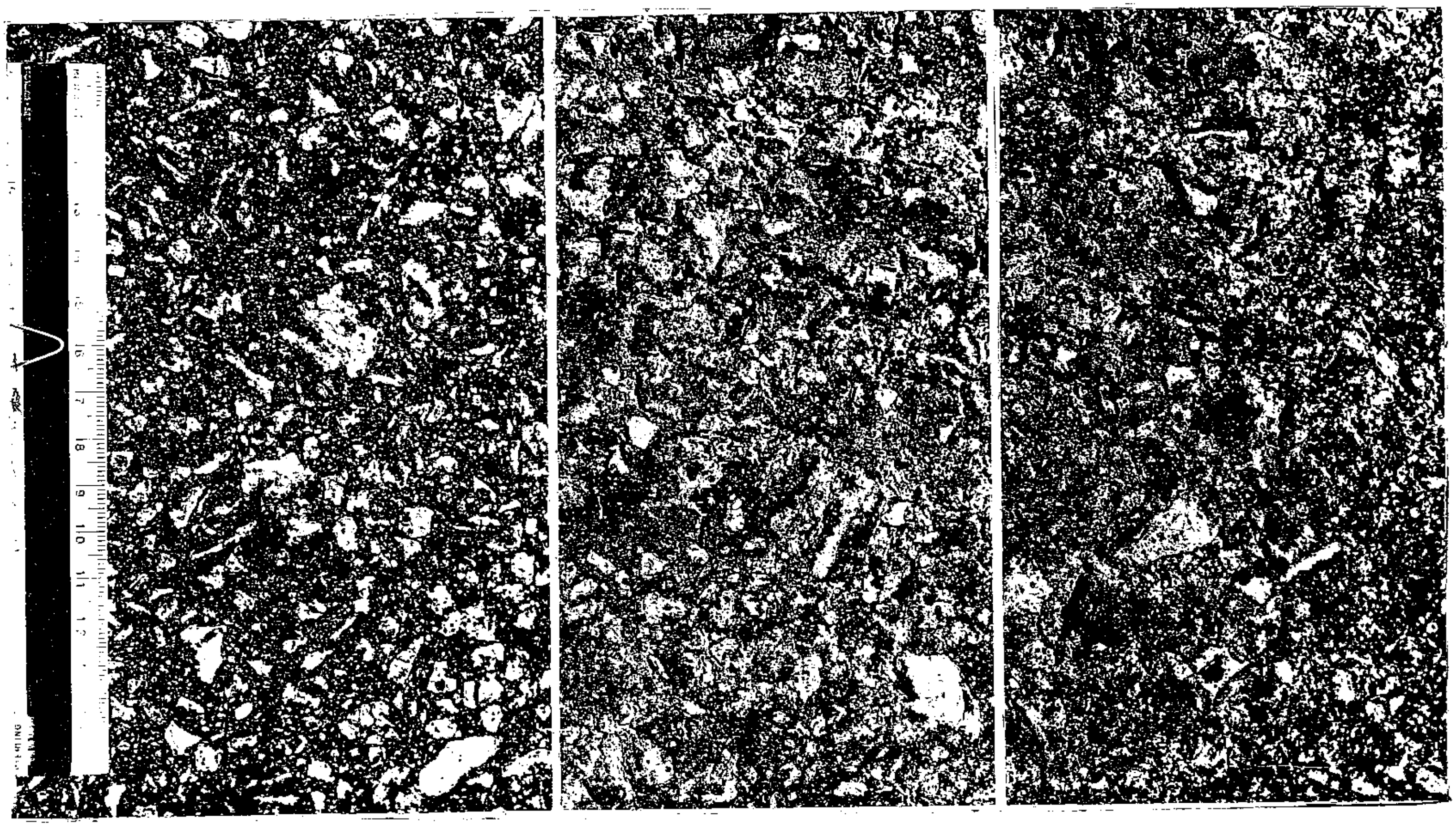
Limestone — Slag

SAND MIXTURES

Limestone — Slag-Limestone — Slag

SURFACE COURSE MIXTURES

Figure 7. Closeup photograph of Sand and Surface Course Mixtures at Troy.



Limestone Slag-Limestone Slag

Figure 8. Closeup photograph of Binder Course Mixtures at Troy.

microroughness of a pavement surface. Also, as mentioned previously, blending slag with limestone slightly improves macroroughness which provides better water darinage and, consequently, better skid resistance.

This study indicates that adjusting the size and amount of coarse aggregate in a fine, dense-graded bituminous mixture does little to change or to improve the macroroughness (drainage) of that surface. Even though slight improvements are possible, they would be insufficient according to Gallaway and others because slight amounts of precipitation will result in water depths above texture peaks of smooth- or fine-textured (0-0.04 in. texture depth) surfaces, and poor drainage will result. 7/ However, Bohman reported drainage can be achieved by placing an open-graded plant-mix seal surface over a fine dense-graded surface. 8/

RESULTS - SINGLE TEST SECTIONS

Test results for single experimental surfaces at 14 different sites are reported in this section. Each site, which has a different or a similar experimental surface, is exposed to different traffic volumes and environments. A description of each experimental site is presented here along with an evaluation of its skid-resistant qualities.

Crushed Gravel - Danville

A crushed siliceous gravel was used as the principal aggregate in a dense-graded bituminous concrete mixture placed in Danville on Route Illinois 1 at the intersection of Third Street. This experiment consisted of 300-foot test sections placed on the approaches to a signalized intersection. At this location, Illinois 1 is a four-lane, undivided street with a traffic volume of approximately 20,000 vehicles per day.

This experimental mix conformed to Section 406 of the Illinois Standard Specifications for Bituminous Concrete Binder and Surface Courses, Class I, except as follows: (1) the coarse aggregate requirement was deleted, (2) the gradation of the fine aggregate was modified to allow for larger sized particles of the crushed gravel, and (3) the coarse sand was required to be Type C in which the particles have an angular shape. The gradation of the crushed gravel aggregate is given in Table 7, and the composition of the mixture is presented in Table 8.

The mix was laid by conventional machine methods to a nominal compacted thickness of 1/2 inch in June 1969. The following September the surface was initially skid tested after having been exposed to approximately one million axle applications. The results of the tests on the crushed gravel mixture are shown in Figures 9 and 10, with skid number plotted as a function of time of year and as a function of vehicle axle applications. In the 2-year period that this pavement has been monitored, the skid number has remained generally between 30 and 40. The most noticeable trend in the skid resistance of this mix is its seasonal variation. Tests made in spring or in early summer indicated higher skid resistance than those tests made in the fall. The higher skid numbers most likely are the result of the roughening and cleansing of the pavement surface during the winter months when abrasives are used for ice control. The use of studded tires during the study period was insignificant.

After 10 million vehicle axle applications, the skid resistance of the crushed gravel mixture is in the marginal performance range of 30 to 36. However, because the mix is at an urban intersection where vehicle speeds are about 25 mph, the skid resistance of the mix probably is adequate for the demands at this site.

TABLE 7

TYPICAL GRADATION OF CRUSHED SILICEOUS GRAVEL - DANVILLE

Sieve Size Passing	Sieve Size Retained	Sample (Percent Retained by Weight)
1/2 inch	No. 4	44.3
No. 4	No. 10	51.2
No. 10	No. 40	3.9
No. 40	No. 80	0.2
No. 80	No. 200	0.1
No. 200	---	0.3

TABLE 8

TYPICAL COMPOSITION OF BITUMINOUS CONCRETE WITH CRUSHED SILICEOUS GRAVEL - DANVILLE

Sieve Size		Percent Retained by Weight	
Passing	Retained	Plant Report	Extraction (Behind Paver)
1/2 inch	No. 4	14.8) 59.1	19.1) 58.4
No. 4	No. 10	44.3)	39.3)
No. 10	No. 40	16.7)	15.7)
No. 40	No. 80	9.4) 30.8	8.8) 30.1
No. 80	No. 200	4.7)	5.6)
No. 200	---	4.7	6.1)
Bitumen (AC 70-85)		5.4	5.4

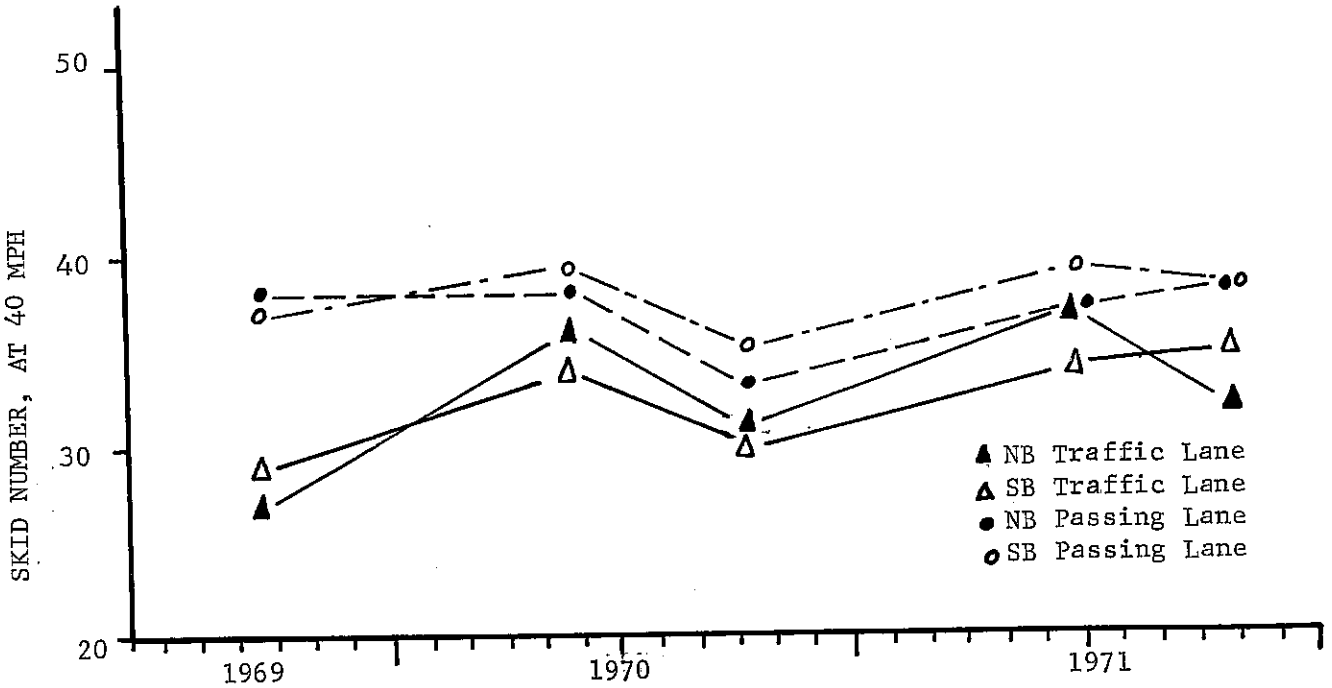


Figure 9. Graph illustrating seasonal variation of skid number for crushed gravel mix at Danville.

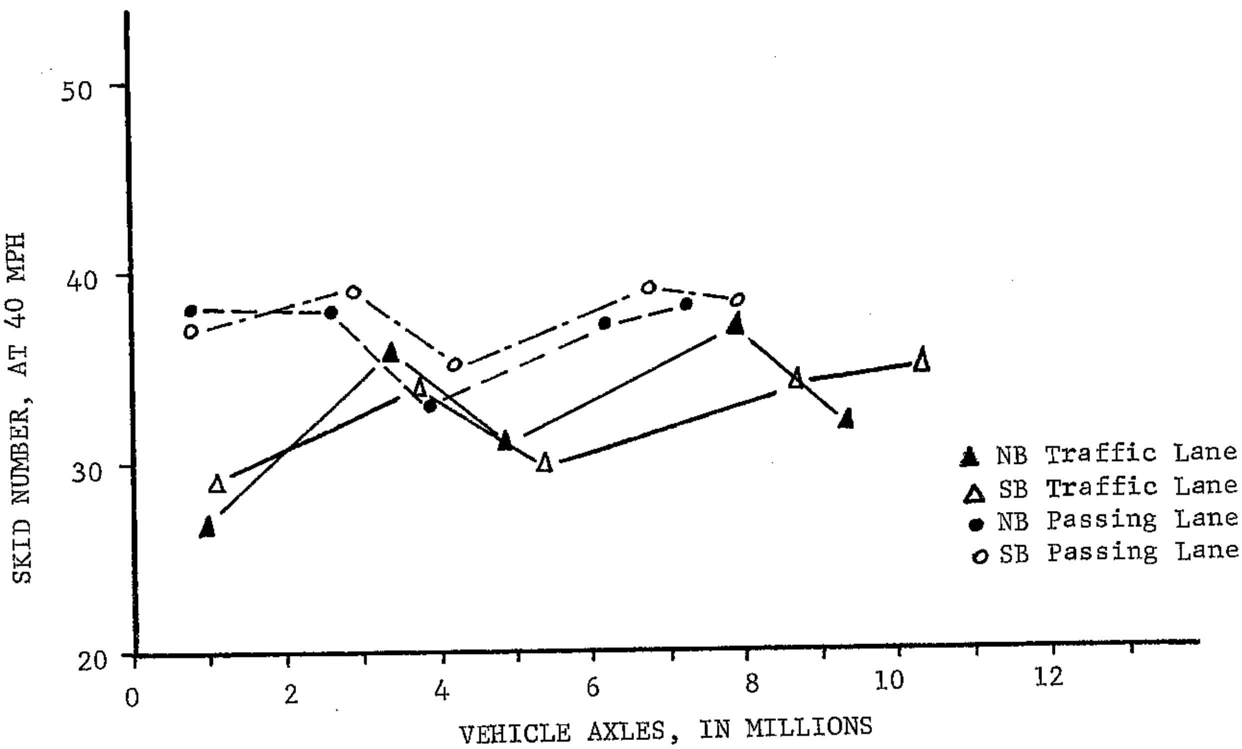


Figure 10. Graph of skid number versus accumulated vehicle axles for crushed gravel mix at Danville.

Ramflex Mix - Glen Ellyn

A bituminous concrete mixture containing dolomitic limestone aggregate and a reclaimed rubber additive called Ramflex was placed on Main Street in the Village of Glen Ellyn. This experimental installation is approximately 2 miles long and is located in a residential neighborhood. Main Street is a two-lane pavement with an average daily traffic of 8,000 vehicles and a posted speed limit of 25 mph.

The Class I bituminous concrete mix modified with Ramflex conforms to the Illinois Standard Specifications except that the Special Provisions required the addition of vulcanized reclaimed rubber intended for use with asphalt and aggregate for paving. In this application, Ramflex was added at the rate of 8 pounds per ton of mixture. A typical gradation of the Ramflex additive is shown below:

Sieve Size		Percent Retain (By Weight)	
Passing	Retained	Specification Limits	Sample
-	No. 4	0 - Trace	0.6
No. 4	No. 8	8 - 27	20.6
No. 8	No. 12	8 - 35	10.2
No. 12	No. 20	13 - 42	25.8
No. 20	No. 35	13 - 35	23.2
No. 35	-	4 - 18	19.6

The Ramflex mix was machine laid to a nominal thickness of 1 inch in October of 1968. Typical extraction test results of the bituminous concrete mixture are presented in Table 9. Located within the 2-mile test section was a 1,000-foot length of regular Class I mix which was used as a control section for comparative purposes. The regular Class I surface was one lane wide and was placed by an asphalt paver to a nominal thickness of 1 inch.

Initial skid tests were made on the Ramflex and the regular Class I mixtures in November of 1969. At this time the pavement had been exposed to nearly three million vehicle axles. Subsequent tests were made in May 1971 and August 1972. The results of these skid tests are given below.

TABLE 9

TYPICAL COMPOSITION OF BITUMINOUS CONCRETE WITH RAMFLEX RUBBER - GLEN ELLYN

Sieve Size		Percent Retained (By Weight)			
Passing	Retained	Plant Report		Extraction (Behind Paver)	
1/2 inch	No. 4	32.2)	54.8	31.9)	53.7
No. 4	No. 10	22.6)		21.8)	
No. 10	No. 40	13.5)		17.0)	
No. 40	No. 80	15.9)	34.8	13.3)	35.0
No. 80	No. 200	5.4)		4.7)	
No. 200	---	4.3		4.9	
Bitumen*		6.0		6.4	

* Includes Ramflex rubber additive.

Date of Test	Number of Axles (Millions)	Skid Number Ramflex	Skid Number Class I
November 1969	2.8	28	29
May 1971	7.0	37	34
August 1972	10.5	36	34

Although the initial tests were low for both the experimental and the control mixtures, later tests suggest that after seven million axle passes the skid resistance of both surfaces has raised to and is maintaining a marginal level.

Normally, Ramflex is added to a bituminous mixture to modify the behavior of the asphalt binder as temperature changes. Apparently, adding Ramflex to a mix does not significantly affect the skid resistance of the pavement surface. Although it does not increase the skid resistance of the pavement, equally important is the fact that it does not act to lower the skid number substantially.

Stone Sand - Odell

A bituminous hot-mix sand seal containing stone sand (limestone) as the primary aggregate was placed on Route US 66 at Odell Road near Odell in Livingston County. The mix was placed on the approaches to the intersection for a distance of 300 feet to the north and to the south. At this signalized intersection, Route US 66 is a four-lane divided highway with a posted speed limit of 45 mph and an ADT of 13,000 vehicles.

This experimental anti-skid mix conformed to the Standard Specifications except that stone sand (limestone) was specified as the aggregate and that the gradation was modified to produce a fine mix; 99 percent of the aggregate passed the No. 4 sieve (Table 10). A fine mix was considered desirable for the placement of a thin overlay. The composition of this mix is presented in Table 11. This material, which was placed in November 1970, was machine laid and was compacted to a nominal thickness of 1/2 inch.

TABLE 10

TYPICAL GRADATION OF STONE SAND - ODELL

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
3/8 inch	100	100
No. 4	93 ± 7	99
No. 10	75 ± 10	82
No. 40	30 ± 7	32
No. 80	13 ± 7	8
No. 200	5 ± 2	4

TABLE 11

TYPICAL HOT-BIN ANALYSIS OF STONE SAND MIXTURE - ODELL

Sieve Size Passing	Retained	Sample Percent Retained (By Weight)	
3/8 inch	No. 4	0.9)	16.1
No. 4	No. 10	15.2)	
No. 10	No. 40	44.7)	
No. 40	No. 80	21.5)	70.2
No. 80	No. 200	4.0)	
No. 200		7.2	
Bitumen 70-85		6.5	

Initial skid tests were made in December 1970. At that time, the surface had been subjected to approximately 400,000 vehicle axles in the traffic lanes and to approximately 100,000 axles in the passing lanes.

The results of the skid tests made on this stone sand mix are given in Figures 11 and 12 which show the skid number as a function of both time of year and number of vehicle axles. The skid test measurements indicate that the stone sand mix initially had a high skid resistance, but as the surface became worn, the skid number decreased to the marginal performance range of 30 to 36 in the traffic lane.

When the skid numbers for the traffic and the passing lanes are compared on the basis of the time of year when the tests were conducted, the passing lanes appear to have consistently better skid resistance. This is, in fact, true only because of the difference in traffic volumes between traffic and passing lanes. When the skid numbers for the lanes are compared on the basis of the vehicle axle applications in Figure 12, the reduction in skid number in the passing lanes is following the same trend as that in the traffic lanes. As the number of vehicle axles in the passing lanes approach the three million mark, skid resistance of the passing lane is expected to level off in the same range as that of the traffic lanes. For the stone sand mix at this location, the majority of the wear has taken place within three million vehicle axle applications, and the addition of two million more axles has not significantly affected the skid number.

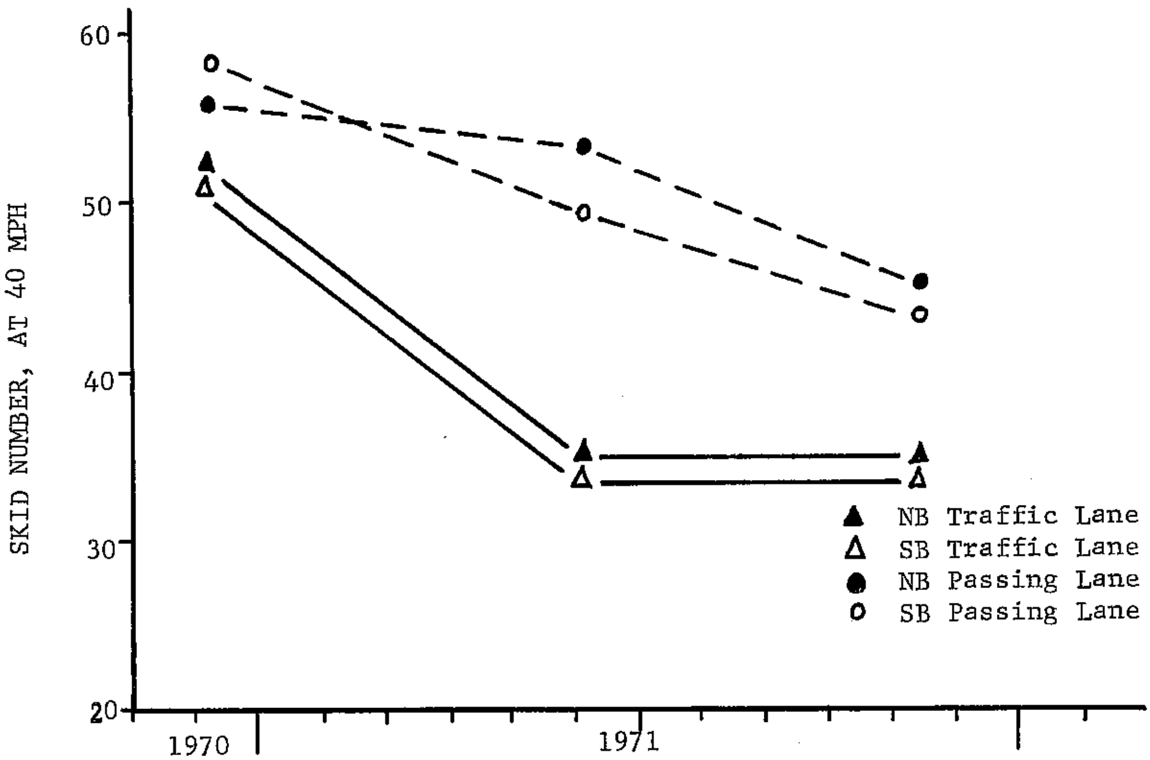


Figure 11. Graph of skid number as a function of time for stone sand mix on US 66 at Odell.

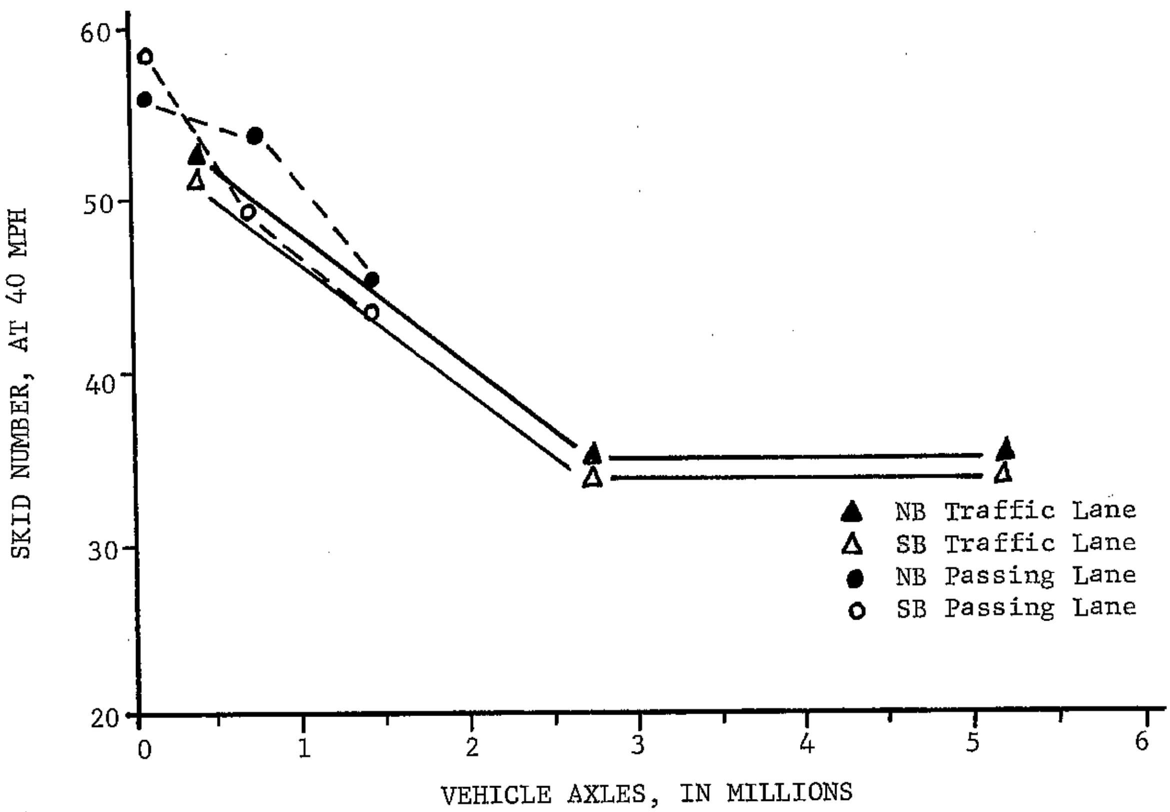


Figure 12. Graph showing decrease in skid number with accumulation of axle passes for stone sand mix on US 66 at Odell.

Stone Sand - 25th Avenue at Eisenhower

A bituminous hot-mix seal coat containing stone sand (limestone) as the primary aggregate was placed on the 25th Avenue structure over the Eisenhower Expressway in Cook County. The bridge carries a four-lane undivided roadway with an ADT of 23,000 vehicles, and 25th Avenue has a speed limit of 35 mph.

The hot-mix seal coat conformed to the Standard Specifications or Class I Bituminous Concrete with the provision that stone sand be used as the primary aggregate. The specification limits and a typical gradation for stone sand are presented in Table 12. Results of an extraction for the mix are given in Table 13.

This mix was machine laid to a nominal thickness of 3/4 inch in October 1969, and initial skid tests were made in November of the same year. At that time the southbound traffic lane had been exposed to about 800,000 vehicle axles, while the northbound traffic lane and both passing lanes had been exposed to about 300,000 axles.

The results of skid tests for this mix are shown in Figures 13 and 14, and indicate a marginal skid resistance in all lanes except the southbound traffic lane, which is acceptable. The southbound traffic lane exhibits the same wear behavior as the northbound traffic lane but is consistently about 10 skid numbers lower than that of the northbound lane.

The reason for a greater number of vehicle axles in the southbound than the northbound lanes in Figure 14 is the traffic-flow pattern at this site, which is a partial cloverleaf interchange for the Eisenhower Expressway. The traffic pattern is such that all southbound vehicles headed for Chicago's Loop pass over the experimental surface as they proceed to the southbound interloop ramp which joins the eastbound expressway, but returning vehicles leave the

TABLE 12

TYPICAL GRADATION OF STONE SAND - 25TH AVENUE

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
3/8 inch	100	100
No. 4	85 - 100	100
No. 10	65 - 95	82.7
No. 40	15 - 40	28.6
No. 80	5 - 20	14.4
No. 200	1 - 6	6.7

TABLE 13

TYPICAL EXTRACTION TEST RESULTS OF STONE SAND MIXTURE - 25TH AVENUE

Sieve Size	Percent Passing (By Weight) (Sample Behind Paver)
3/8 inch	100
No. 4	99.2
No. 10	94.2
No. 40	36.9
No. 80	18.4
No. 200	8.2
Bitumen (AC85 - 100)	6.9

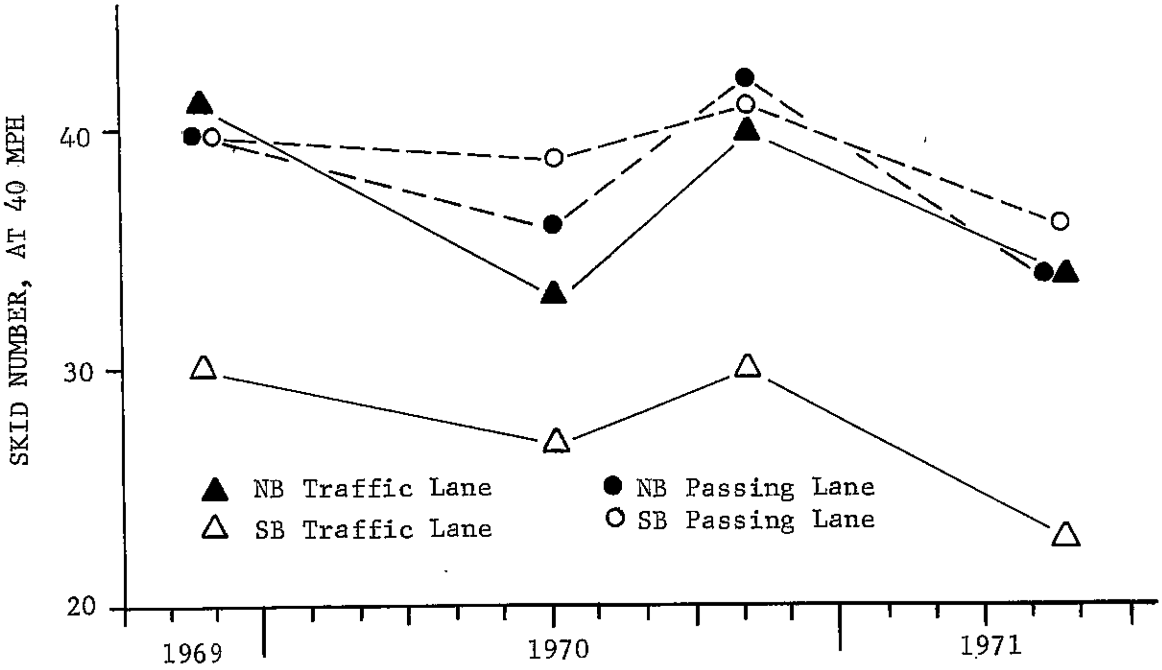


Figure 13. Graph of skid number versus time for stone sand mix at 25th Avenue over Eisenhower Expressway.

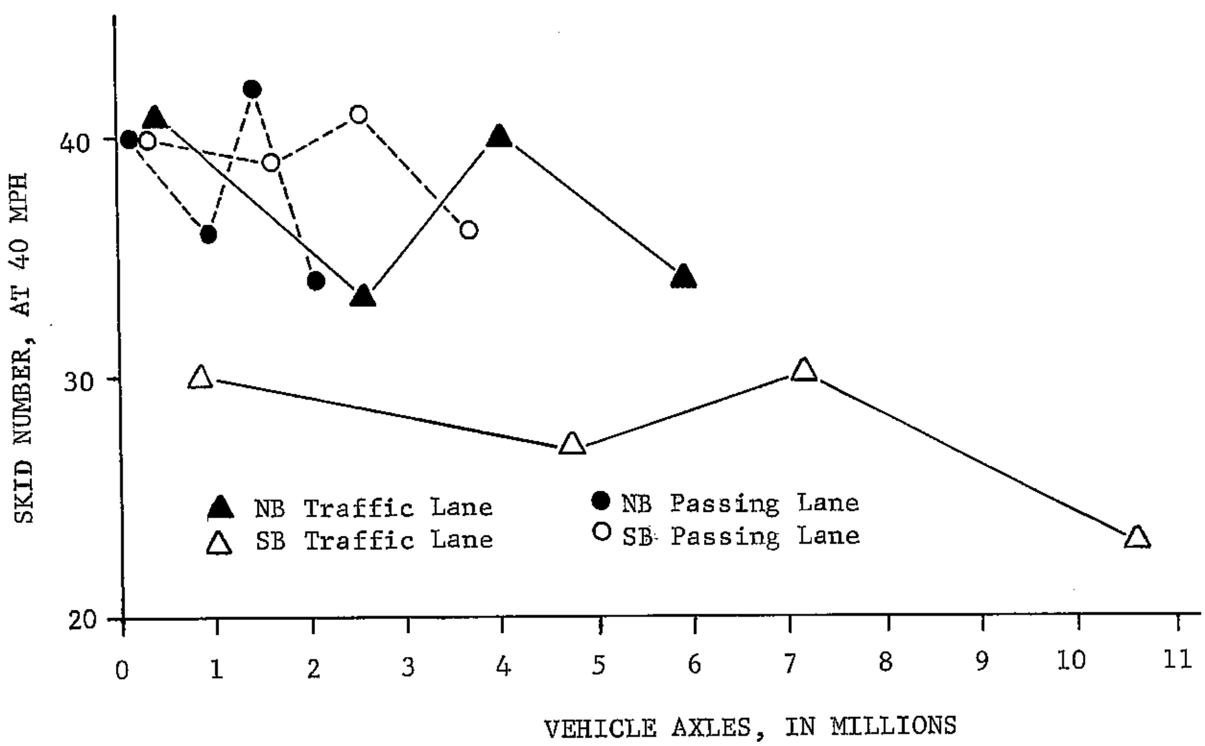


Figure 14. Graph of skid number versus accumulated axle passes for stone sand mix at 25th Avenue over Eisenhower Expressway.

expressway by the northbound outer ramp which merges with 25th Avenue beyond the experimental area. That portion of traffic destined for Chicago constitutes approximately one half of the volume in the southbound traffic lane. Consequently, the wear in this lane is approximately twice that of the northbound lane.

No explanation for the initial difference in skid numbers between the northbound and southbound traffic lanes was obtained from the data. It is speculated that the mix placed in the southbound traffic lane may have been somewhat richer in asphalt content.

Stone Sand w/R-504 - Cermak at 25th Avenue

A stone sand bituminous concrete mix with a rubber additive was placed on the Cermak Road structure over 25th Avenue in Cook County. The Cermak Road structure carried four undivided lanes over 25th Avenue with a posted speed limit of 35 mph and has an ADT of 23,000 vehicles.

This bituminous hot-mix seal coat conforms to the Standard Specifications for Class I Bituminous Concrete except that stone sand (limestone) was used as the principal aggregate and that a rubber additive was specified in the Special Provisions. The rubber additive, manufactured by Firestone Tire and Rubber Company under the trade name of R-504, is an unvulcanized synthetic liquid rubber and constitutes 0.4 percent (by weight) of the total mix. A typical gradation of stone sand is shown in Table 14, and the composition of the mix is given in Table 15.

This rubberized sand mix was machine laid to a nominal thickness of 3/4 inch. The material was placed in October 1969 and was skid tested initially in November of the same year. At the time of the first skid tests, the traffic lanes

TABLE 14

TYPICAL GRADATION OF STONE SAND WITH R-504 RUBBER - CERMAK ROAD

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
No. 4	100	100
No. 10	90 - 100	94.9
No. 40	50 - 80	60.1
No. 80	15 - 40	23.3
No. 200	5 - 10	2.5

TABLE 15

TYPICAL EXTRACTION TEST RESULTS FOR STONE SAND WITH R-504 RUBBER - CERMAK ROAD

Sieve Size	Sample (Percent Passing)
No. 4	100
No. 10	97.6
No. 40	65.4
No. 80	31.7
No. 200	5.6
Bitumen	8.3

had been subjected to 800,000 vehicle axles, whereas the passing lanes had been subjected to nearly 300,000 axles.

The results of the skid tests on the rubberized sand mix are shown in Figures 15 and 16, which give the skid number as a function of the time of year tested and as a function of the number of vehicle axles passing over the site. When the surface was new, its skid resistance was acceptable, but as the number of axle applications approached 3-4 million, the skid number entered the marginal range, which is a skid number between 30 and 36. The skid number then remained relatively constant through additional axle applications exceeding the 10 million mark. In the summer of 1972 when the site was last observed, the thin stone sand surface was in excellent condition; only two small areas less than one half square foot have exposed the underlying pavement.

Natural Sand - Urbana

A natural sand asphalt hot-mix was placed on two residential streets in the City of Urbana as experimental mixes in their street maintenance program. Engineers in Urbana who were experimenting with thin bituminous overlays for street maintenance requested skid tests on the sand asphalt mixes. The sand mix was placed on Pennsylvania Avenue and on Crystal Lake Drive, both of which have 25 mph speed limits and have relatively low traffic volumes. Pennsylvania Avenue has an annual ADT of 700 vehicles, and Crystal Lake Drive has an ADT of 350 vehicles.

The sand mix used at these sites was designed such that 5 to 10 percent of the aggregate would be retained on or above the No. 4 Sieve. The natural sand in the mix was Type A, which is a rounded type particle, and a typical gradation of the sand is given in Table 16. The composition of the total mix is given in Table 17 which is a typical hot-bin analysis for the natural sand asphalt mix.

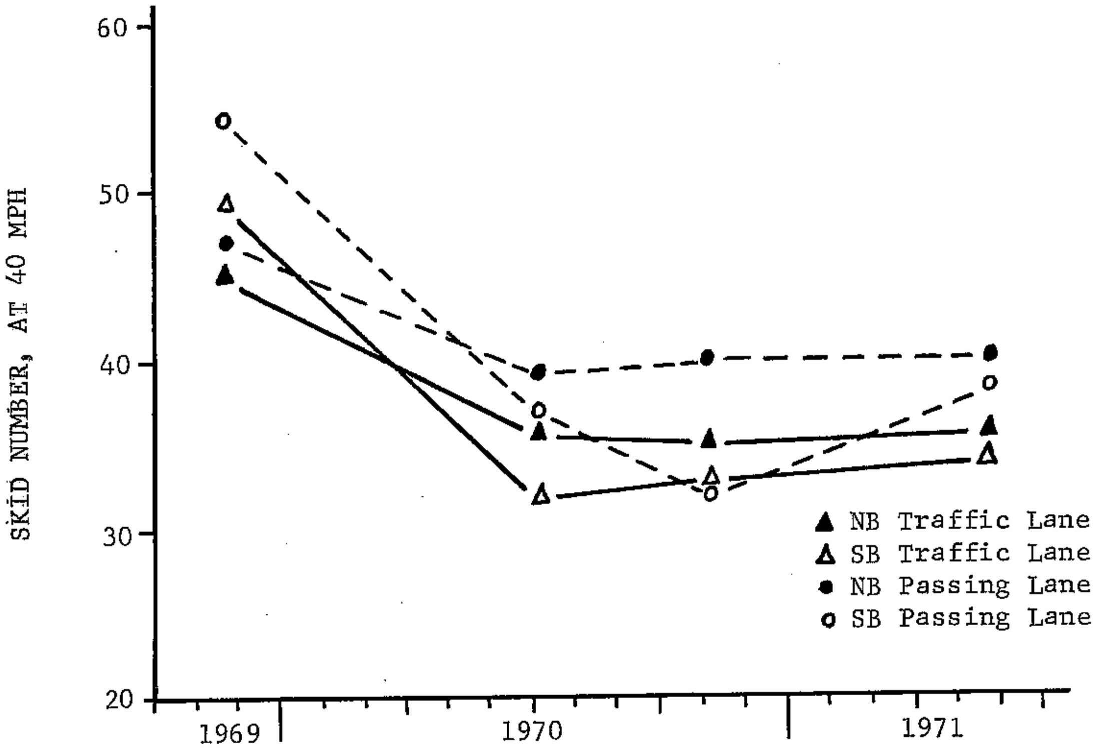


Figure 15. Graph of skid number versus time for rubberized stone sand mix on Cermak Road at 25th Avenue.

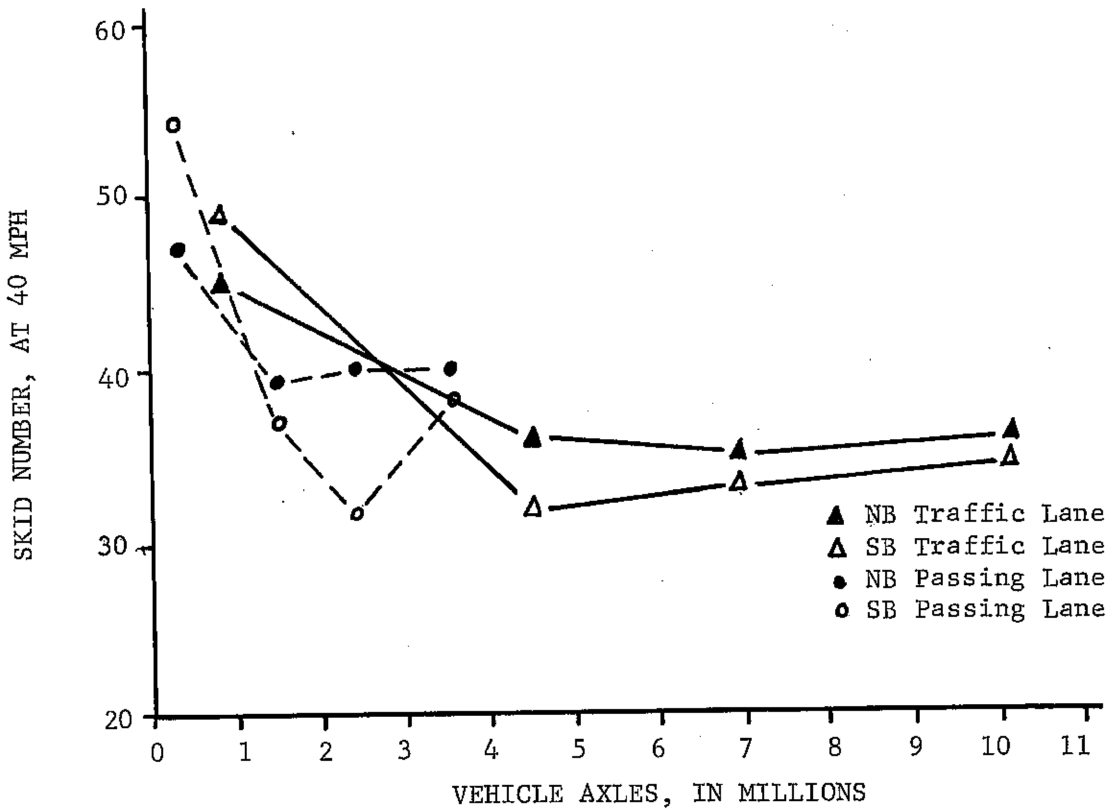


Figure 16. Graph showing decrease in skid number with accumulation of axle passes for rubberized stone sand mix on Cermak Rd. at 25th Ave.

TABLE 16

TYPICAL GRADATION OF NATURAL SAND - URBANA

Sieve Size	Percent Passing (By Weight) Fine Sand	Coarse Sand
1/2 inch		100
No. 4		94.8
No. 10	100	82.0
No. 40	98	26.1
No. 80	14.8	2.8
No. 200	2.7	1.1

TABLE 17

TYPICAL HOT-BIN ANALYSIS OF NATURAL SAND ASPHALT MIX - URBANA

Sieve Size Passing	Retained	Plant Report (Percent Retained)	
1/2 inch	No. 4	3.9)	12.6
No. 4	No. 10	8.7)	
No. 10	No. 40	64.1)	
No. 40	No. 80	13.8)	79.3
No. 80	No. 200	1.4)	
No. 200		1.6	
Bitumen (AC 85-100)		6.5	

The mix was placed at a nominal thickness of 3/4 inch by conventional methods in November 1969 and was first skid tested in October 1970. Within this period, the test site on Pennsylvania Avenue had been subjected to above 250,000 vehicle axles while the site on Crystal Lake Drive had been subjected to about 120,000 axles. The results of skid tests at test sites on Crystal Lake Drive and Pennsylvania Avenue are as follows:

Location	Date of Test	Number of Axles (Millions)	Skid Number, 40 MPH EB	Skid Number, 40 MPH WB
Cyrstal Lake Drive	10-70	0.12	57	53
	9-71	0.23	57	57
	10-72	0.38	60*	58*
Pennsylvania Avenue	10-70	0.24	58*	58*
	9-71	0.47	55	58
	10-72	0.69	60	59

* Tests conducted at 30 mph adjusted to 40 mph

Although the accumulative number of vehicle axles that have passed over both sites is still relatively low, both sites have maintained acceptable skid numbers in the high 50's for nearly three years since placement.

Natural Sand - Effingham

A dense-graded bituminous concrete mixture with natural sand as the aggregate was placed on Route US 40 east of Effingham. At this location, Route US 40 is a two-lane, rural highway with an ADT of 5,000 vehicles.

This experimental mixture, which is a modified Class I surface course, conforms to the Standard Specifications for Road and Bridge Construction, except that the Special Provisions deleted the use of coarse aggregate and prohibited the use of stone sand or stone screenings as fine aggregate. The natural sand used in the mix was Type A which is a rounded type particle, and a sample gradation of the sand used may be seen in Table 18. The use of a fine round sand allowed construction of a 1/2-inch-thick overlay with good workability. The composition of this mix is presented in Table 18.

In addition to the sand mix, a regular Class I surface course mix including a natural sand (Type A) as fine aggregate was placed at a nominal thickness of 1 1/2 inches adjacent to the experimental test section for comparative purposes. As can be seen in Table 19, the composition of the coarse Class I mix can be compared with the fine sand mix. Both mixtures were placed in August 1970 and were skid tested in September of that same year. When initial skid tests were made, the site had been exposed to approximately 150,000 vehicle axles.

The results of the skid tests made on the two overlays are shown in Figures 17 and 18. The measured skid numbers are presented both as a function of time and as a function of vehicle axles passing over the site. Initial tests indicated that the skid resistance of the sand mix was slightly below the marginal range of 30 to 36, but after approximately two million axles had passed over the site, the skid resistance had increased well into the marginal range.

Results of tests made on the regular Class I mix also are shown in Figures 17 and 18. The skid resistance of this mix closely resembles that of the experimental sand mix. After one and one-half million axle applications, the skid resistance of the Class I mix began to increase as did the skid resistance of the sand mix. This increase in skid resistance may be the result of the traffic exposing the aggregate at the surface.

The skid resistance of the experimental sand mix, in general, is not significantly better than that of the regular Class I mix presently being used. The sand mix may provide sufficient skid resistance at locations where vehicle speeds are below 35 mph. At higher speeds the skid resistance most likely would be

TABLE 18

TYPICAL GRADATION OF NATURAL SAND - EFFINGHAM

Sieve Size	Percent Passing (By Weight) Fine Sand	Coarse Sand
No. 4	--	100
No. 10	100	-
No. 16	-	67.4
No. 40	82.5	-
No. 50	-	19.0
No. 80	38.4	-
No. 100	-	2.2
No. 200	6.9	-

TABLE 19

TYPICAL HOT-BIN ANALYSIS OF NATURAL SAND ASPHALT MIX - EFFINGHAM

Sieve Size Passing	Retained	Percent Retained (By Weight) Class I Control		Sand Mix	
3/4 inch	1/2 inch	1.7)			
1/2 inch	No. 4	34.8)	60.7		
No. 4	No. 10	24.2)		9.9	
No. 10	No. 40	14.0)		37.4)	
No. 40	No. 80	14.4)	33.4	26.1)	74.2
No. 80	No. 200	5.0)		10.7)	
No. 200		4.2		8.2	
Bitumen (AC 70-85)		4.7		7.7	

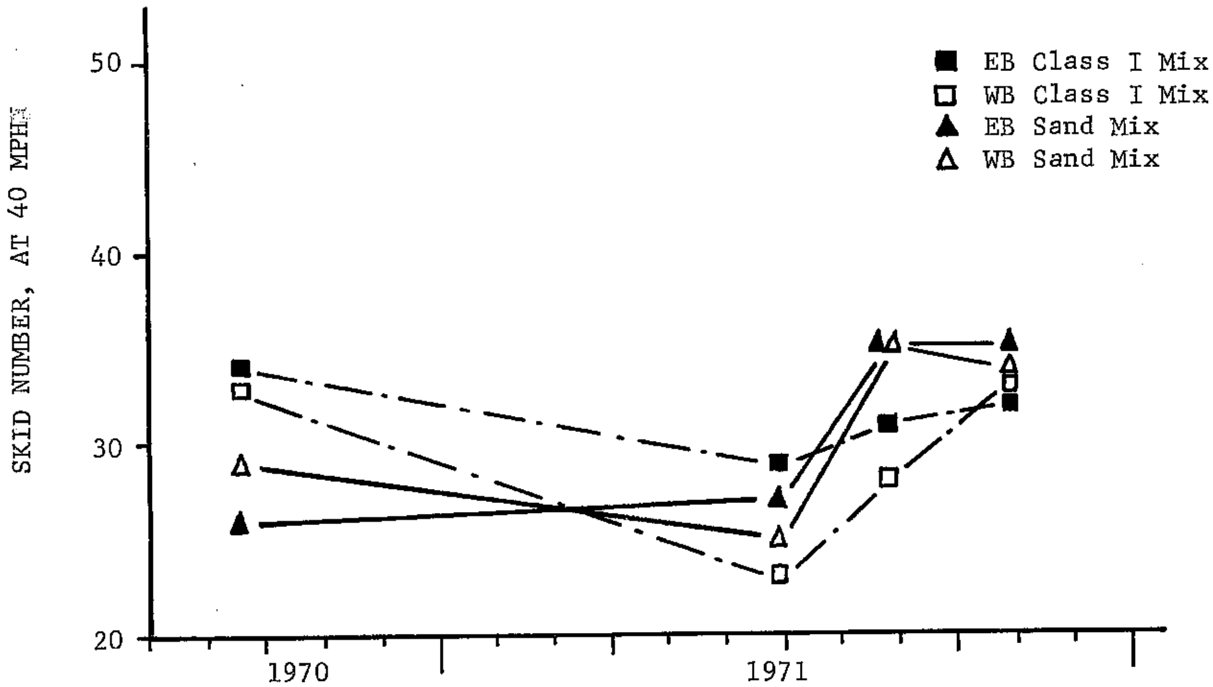


Figure 17. Graph of skid number versus time for both sand and Class I control mixes at Effingham.

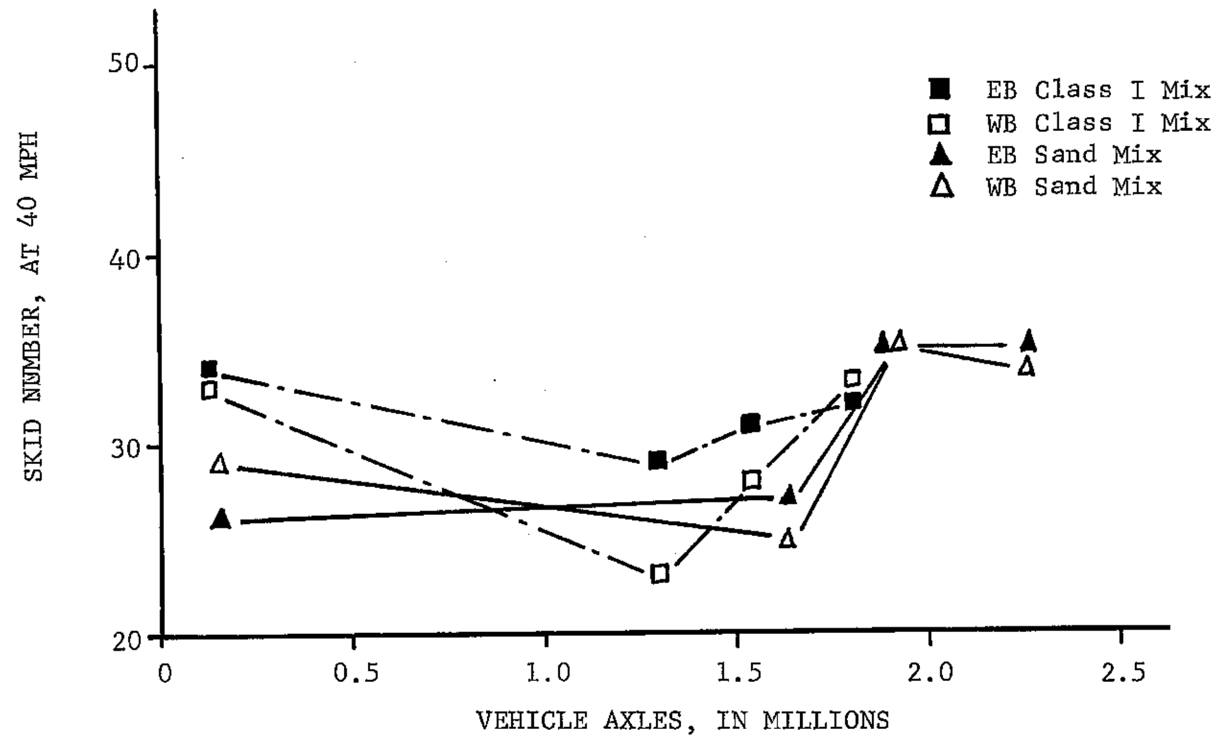


Figure 18. Graph of skid number versus accumulated axles for both sand and Class I control mixes at Effingham.

inadequate, which generally is true of many fine mixes. Fine-textured mixes have lower skid resistance at higher speeds because the fine texture of the surface provides insufficient water drainage necessary for satisfactory skid resistance.

Tapisable - Aurora, Champaign

A sand asphalt mix containing an additive called Tapisable was placed as an experimental mix in the cities of Aurora and Champaign. The same specifications and special provisions were used for the mixtures placed in each city. Of the several experimental sections placed, ten were chosen for testing, eight in Aurora and two in Champaign. The length of each test section varied as did the traffic volume present at each site. All of the sites chosen were located on residential streets with average daily traffic volumes that range from 200 to 5,000 vehicles per day.

The aggregate in the Tapisable mix is a blend of natural sand, limestone screenings, and mineral filler, all of which pass the No. 4 sieve. According to the manufacturer, liquid Tapisable when added to a bituminous mixture containing 6 to 8 percent asphalt provides high workability and affinity of the asphalt binder for the aggregate and good adhesion between the overlay and the existing surface. Also, the manufacturer claimed that a tack coat is unnecessary on most asphalt surfaces prior to applying the Tapisable mixture.

This experimental mix conforms to the Standard Specifications for Class I bituminous concrete except that the gradation of the aggregate was modified to provide for a finer mix and that the addition of the liquid Tapisable was specified. The gradation of the aggregate specified is as follows:

Sieve Size	Percent Passing (By Weight)
No. 4	100
No. 10	65 - 90
No. 20	40 - 80
No. 40	25 - 60
No. 80	10 - 25
No. 200	6 - 10

Tapisable was placed first at one location in Aurora in 1966. In May 1967, the City of Champaign placed a 5/8-inch-thick overlay of Tapisable on two residential streets. Three years later, in October 1970, the City of Aurora placed Tapisable at several locations throughout the city. The mix was placed by conventional machine methods in Champaign; whereas in Aurora the mix was placed by three different methods; a motor grader equipped with a spreader box, a Layton paver (non-self-propelled type), and a conventional machine paver.

Skid tests for Tapisable mixes in Champaign are shown in Figures 19 and 20, and in Aurora are presented in Figure 21. The primary difference between the two sites in Champaign is the number of vehicle axle applications. The Greencroft site carried a much lower traffic volume than the Sangamon Drive site as can be seen in Figure 20. The Tapisable had an initial skid number near 60, yet after six million axle applications the skid number remained in the high 40's.

Similar performance is seen in skid tests in Aurora. The tests for all locations are plotted on one graph to better illustrate the effect of axle applications on the skid number. As at Champaign, the skid numbers at the Aurora sites are initially near 60, but as the number of axle passes accumulated toward one million, the skid number decreased to 40.

At both Aurora and Champaign, Tapisable has given acceptable performance with as many as six million vehicle axle applications. Tests suggest that the skid number of Tapisable mixtures should not decrease much below 40 when traffic volumes are less than 5,000 vehicles per day.

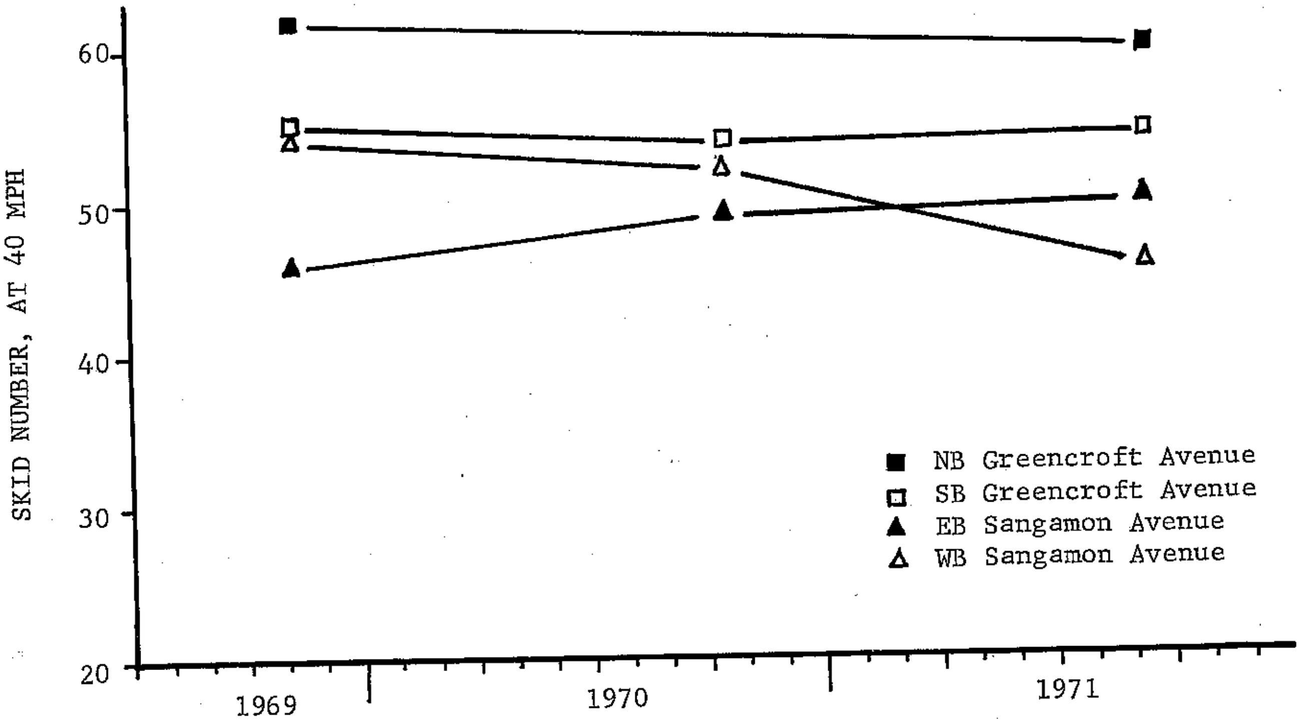


Figure 19. Graph of skid number as a function of time for two residential streets surfaced with Tapisable in Champaign.

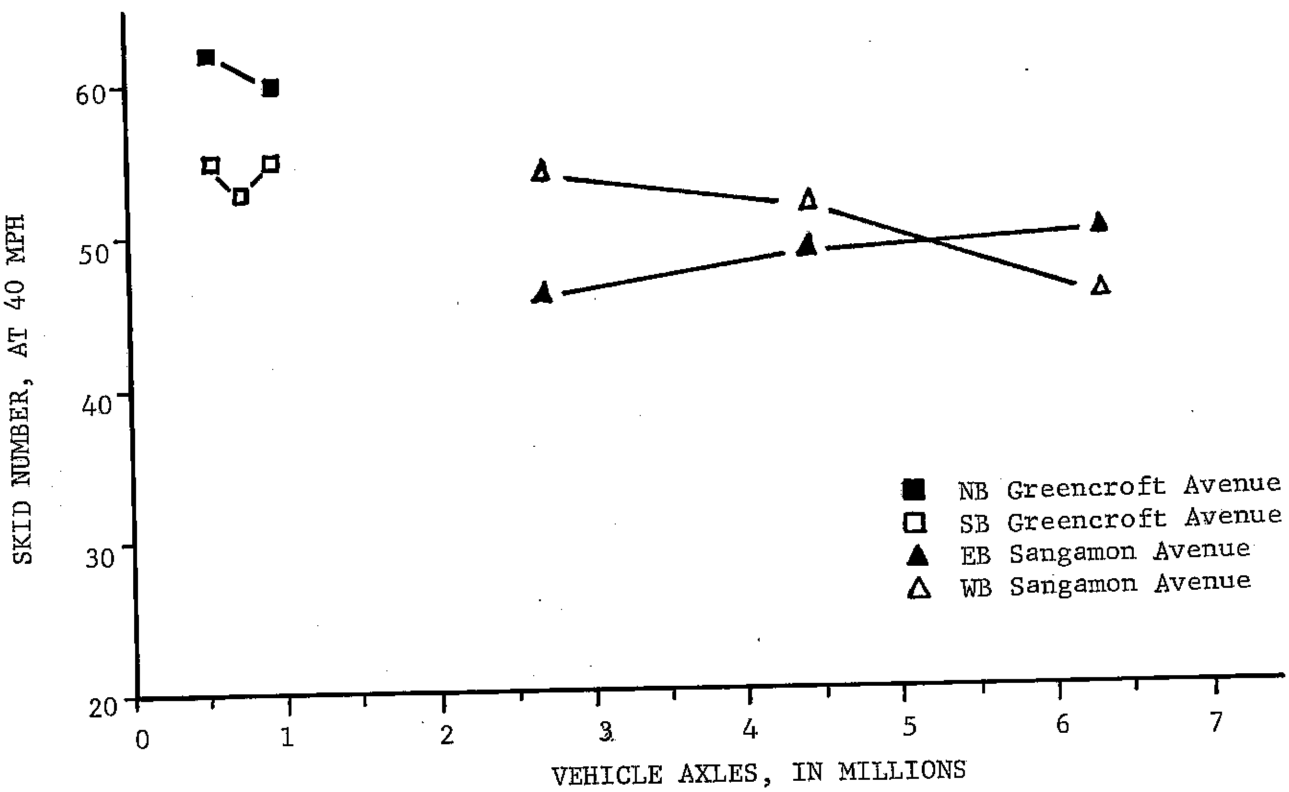


Figure 20. Graph showing effect of accumulated axle passes on skid number for two residential streets surfaced with Tapisable in Champaign.

Trap Rock - Decatur

Trap rock was used as the principal aggregate in a dense-graded bituminous concrete mixture placed at three signalized intersections along Route US 36 (Eldorado Street) in downtown Decatur. At all three intersections, Eldorado Street is a four-lane, undivided street with an ADT that varies from 20,000 to 27,000 vehicles. In this commercial area where the prevailing speed limit is 25 mph, the trap rock mix was placed on the approaches varying from 140 to 400 feet back from the intersection.

This experimental mix is a modified Class I surface course conforming to the Standard Specifications except for the following Special Provisions: (1) the requirement for coarse aggregate was deleted, (2) the fine aggregate was required to be a blend of trap rock and natural sand, and (3) the gradation of the aggregate was modified to provide a greater percentage of fine aggregate.

The trap rock used in this mix was a crushed granite-dolomitic stone derived as a by-product from the extraction of lead and zinc ore and was obtained from Iron Mountain, Missouri. The gradation of the trap rock is given in Table 20 and the composition of the total mixture is given in Table 21.

The mix was laid by a conventional paver to a compacted thickness of 1/2 inch in June 1969 and was skid tested in September of the same year. At the time of these first tests, the pavement had been exposed to vehicle axle passes ranging from 1/2 to 1 1/2 million.

Skid tests of the trap rock mix are shown in Figures 22 through 27 and indicate skid numbers generally varying from 30 to 40. All three of the intersections showed similar variations with respect to the time of year tested. This variation, as seen in the Figures 22, 24 and 26, is related more to seasonal variation than to the number of axle applications. Apparently, mixes containing trap rock are not influenced by wear as much as other softer aggregates.

TABLE 20

TYPICAL GRADATION OF TRAP ROCK MIXTURE - DECATUR

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
3/8 inch	100	100
No. 4	95 - 100	100
No. 10	85 - 95	81.8
No. 40	10 - 30	19.7
No. 80	0 - 10	5.3
No. 200	0 - 5	1.1

TABLE 21

TYPICAL HOT-BIN ANALYSIS OF TRAP ROCK MIXTURE - DECATUR

Sieve Size Passing	Sieve Size Retained	Percent Retained (By Weight) Specification Limits	Sample
3/8 inch	No. 4	0 - 5) 3-15	0) 4.6
No. 4	No. 10	3 - 15)	4.6)
No. 10	No. 40	35 - 75)	31.3)
No. 40	No. 80	5 - 20) 60-90	30.6) 82.9
No. 80	No. 200	3 - 10)	21.0)
No. 200		3 - 9	6.0
Bitumen (AC 70-85)		5.5- 7.5	6.5

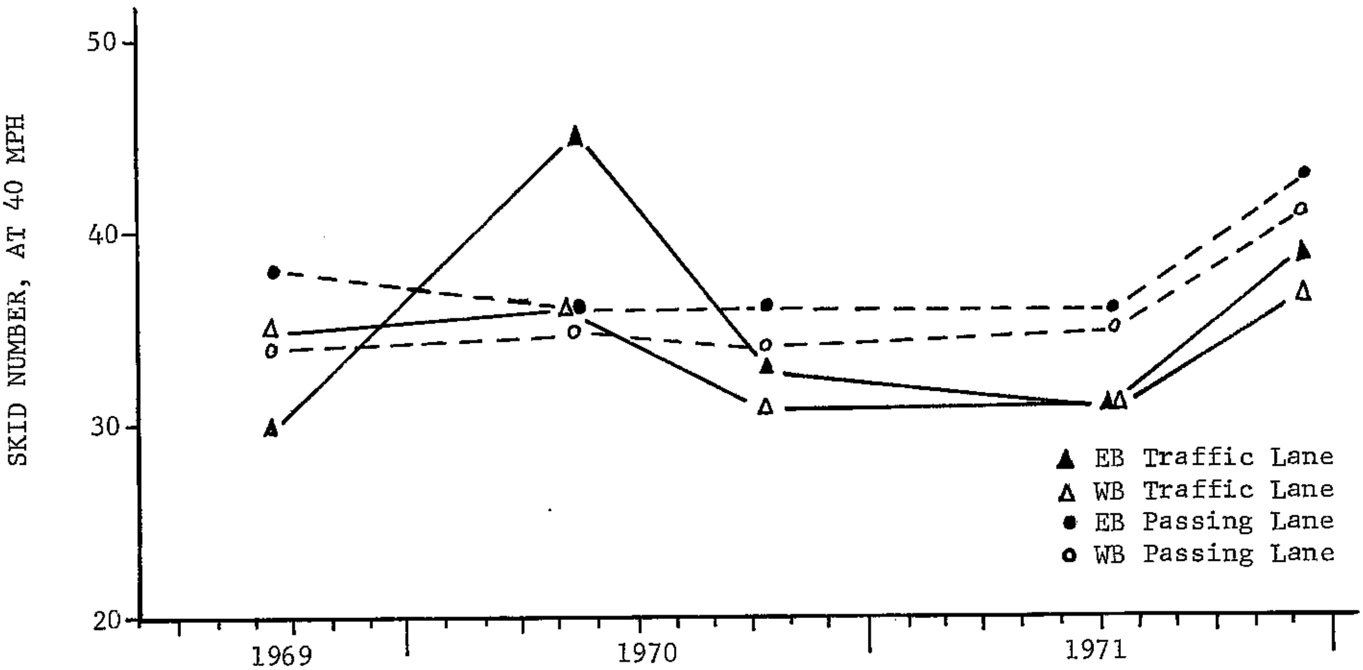


Figure 22. Graph of skid number versus time for trap rock mix at Van Dyke and Eldorado Streets in Decatur.

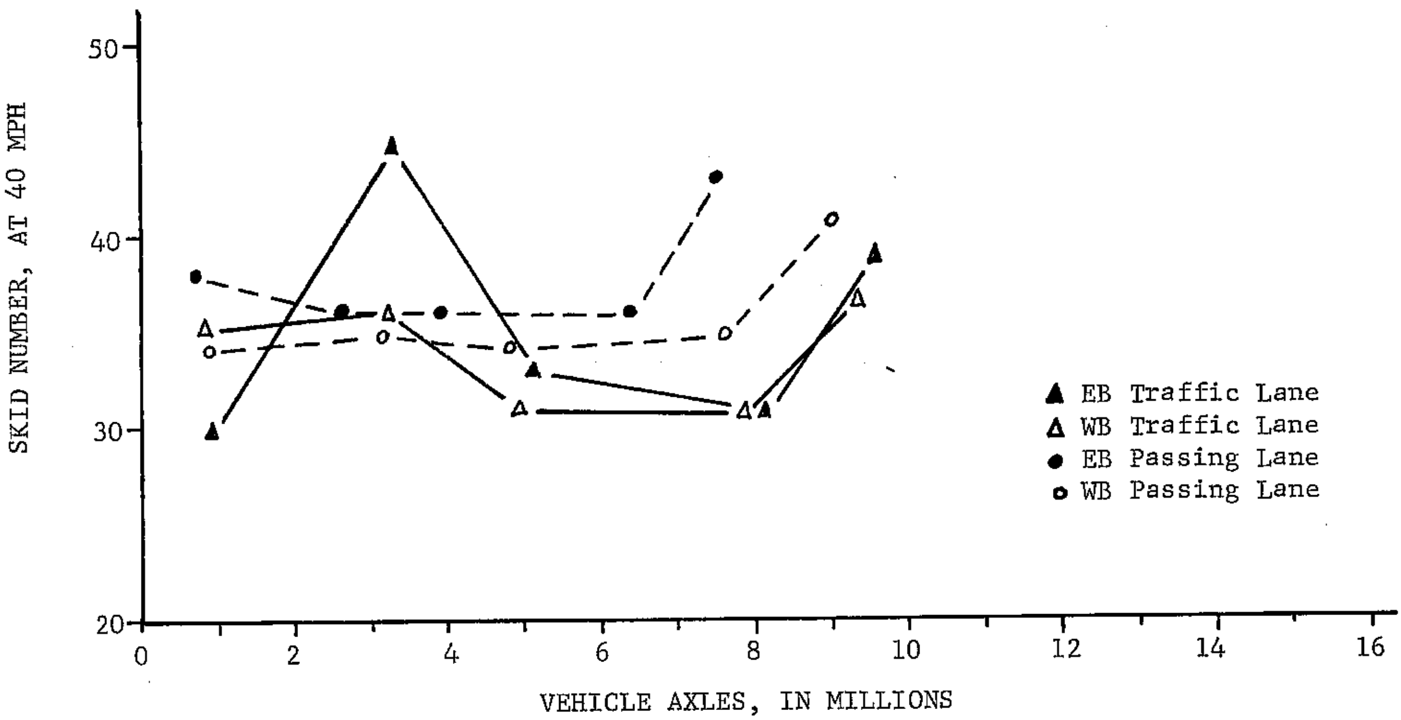


Figure 23. Graph showing effect of accumulated axles on skid number for trap rock mix at Van Dyke and Eldorado Streets in Decatur.

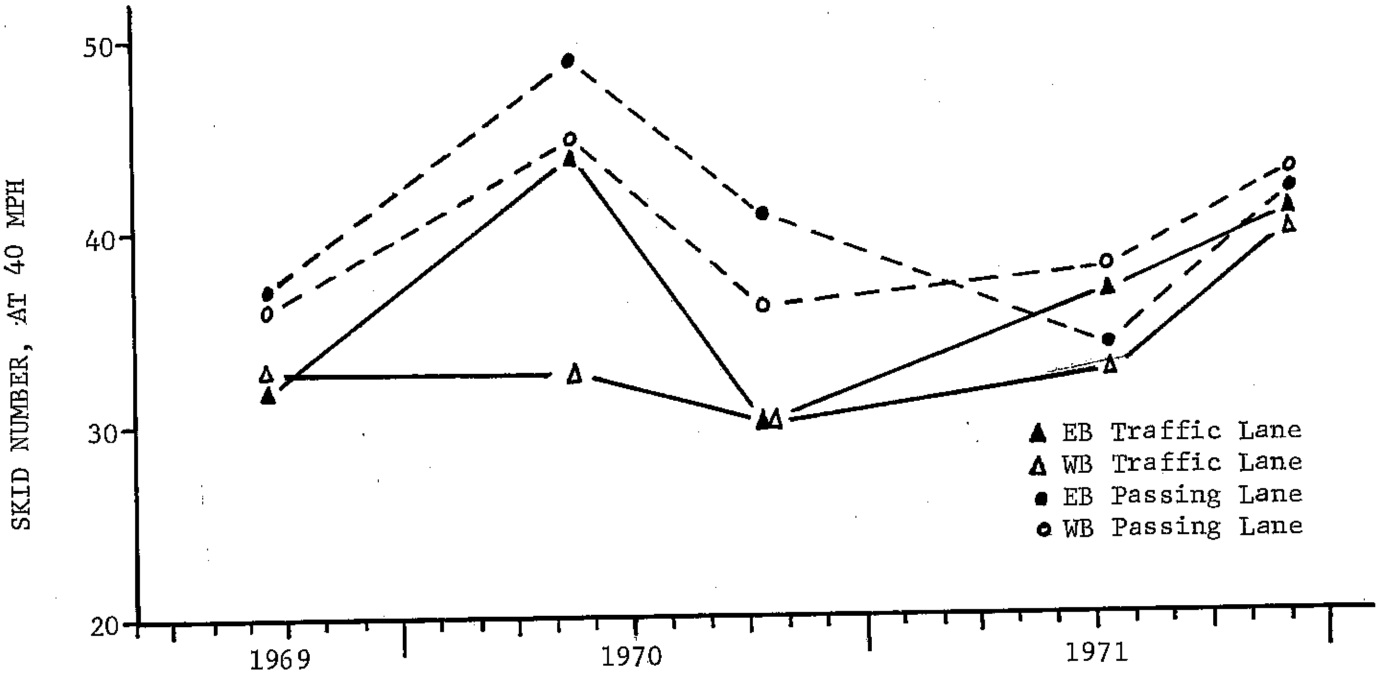


Figure 24. Graph of skid number versus time for trap rock mix at Broadway and Eldorado Streets in Decatur.

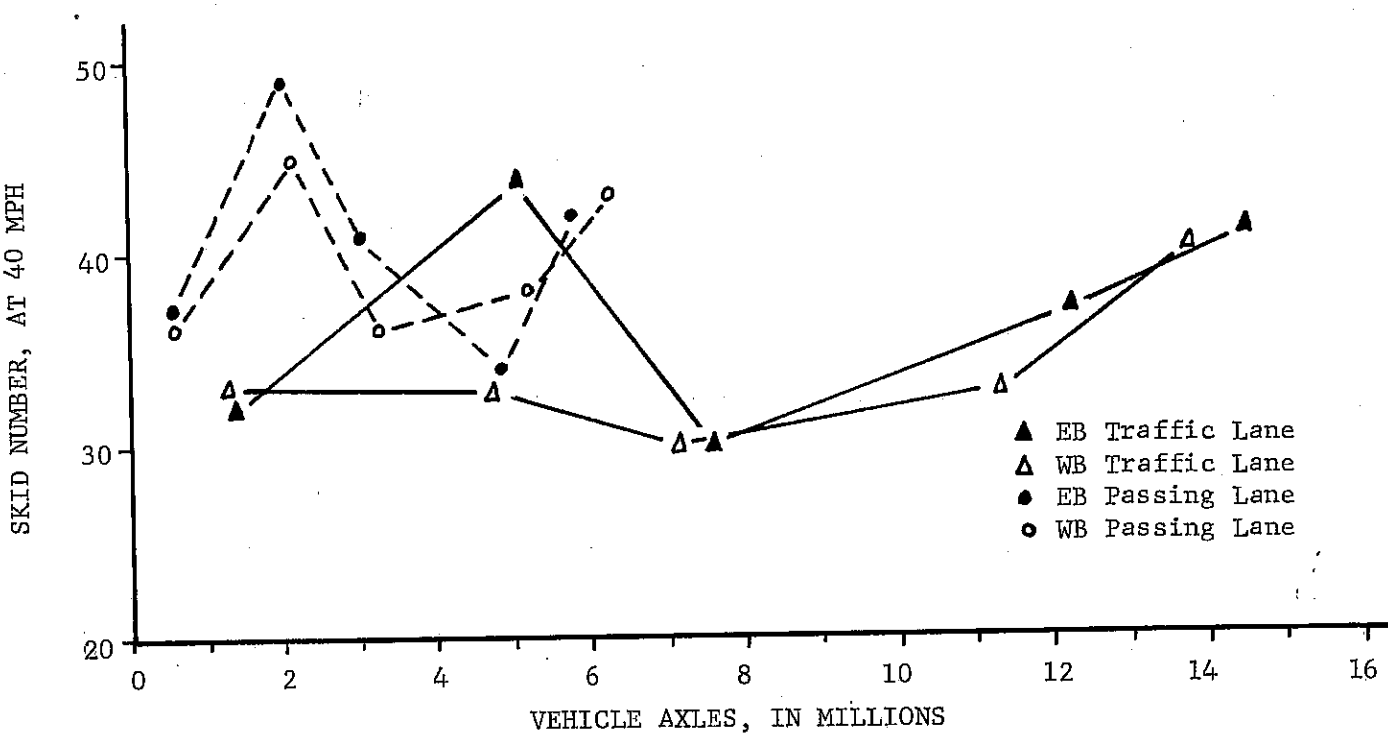


Figure 25. Graph showing effect of accumulated axles on skid number for trap rock mix at Broadway and Eldorado Streets in Decatur.

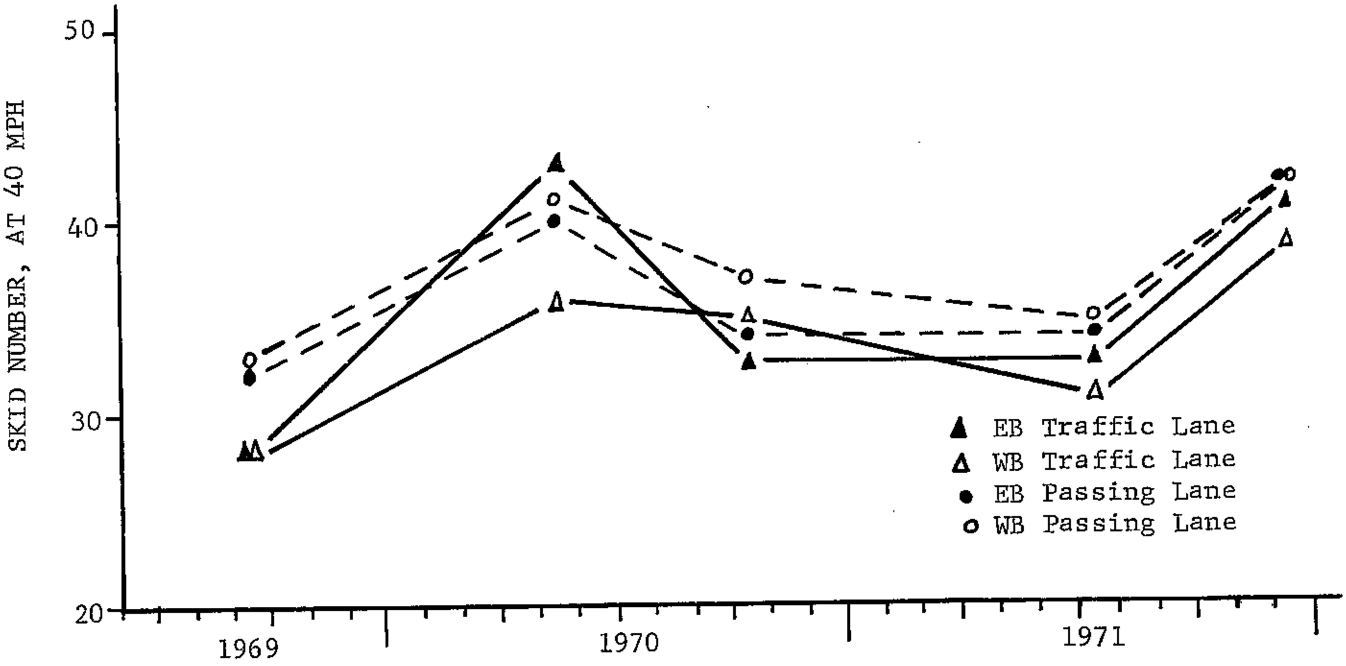


Figure 26. Graph of skid number versus time for trap rock mix at Jasper and Eldorado Streets in Decatur.

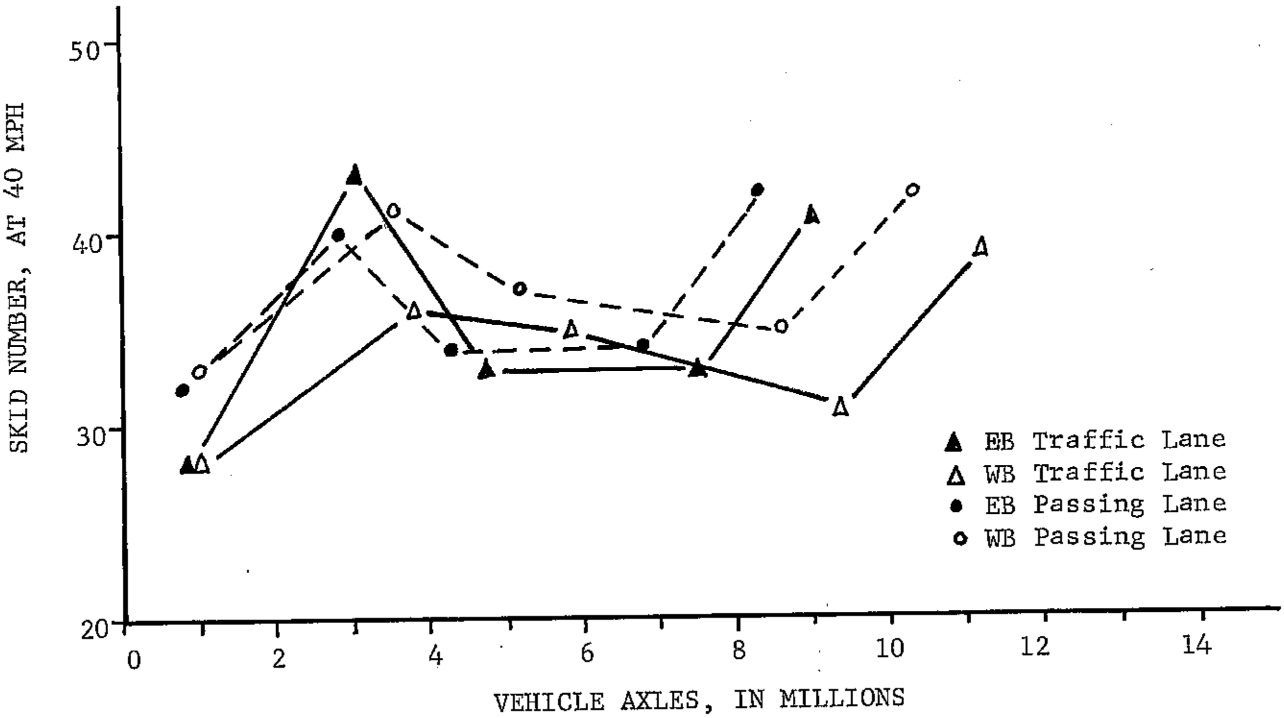


Figure 27. Graph showing effect of accumulated axles on skid number for trap rock mix at Broadway and Jasper Streets in Decatur.

The effect of the season of the year or possibly the temperature of the pavement at the time of the test appears to have a greater influence on these tests than does the effect of axle applications. This is most evident in Figure 24 where the skid number for each lane increases and decreases rather uniformly with the time of year tested, whereas no distinct pattern exists when skid number is given as a function of vehicle axles. Moreover, the wide variation in skid tests made during May 1970 and shown in Figures 22 and 24 resulted when a prime coat applied to Eldorado Street between intersections contaminated the intersections.

On the basis of skid tests made at these three intersections, a fine-textured bituminous concrete containing trap rock as an aggregate has an adjective rating that varies from marginal to acceptable, depending on the time of the year when the surface is tested. Although some skid tests are marginal, they are adequate for operating speeds (25 mph) at these sites.

Trap Rock with Rubber - Lincoln

An experimental bituminous mix containing a Missouri trap rock and a liquid rubber additive was placed on Route US 66 at Fifth Street near Lincoln in Logan County. The mix was placed on both the northbound and the southbound approaches to the signalized intersection, and the length of each overlay was 700 feet. At this intersection, Route US 66 is a four-lane divided highway with a posted speed limit of 45 mph and with an ADT of 13,000 vehicles.

This mix conformed to the Standard Specifications for Class I Bituminous Concrete except that the Special Provisions specified the use of trap rock as the principal aggregate (Table 22) and the use of a rubber compound called R-504 which is manufactured by Firestone Tire and Rubber Company. The liquid rubber additive is an unvulcanized virgin synthetic rubber and constitutes about 0.3 percent (by weight) of the solids of the total mix. The composition of this trap rock mixture is presented in Table 23.

The mix was placed 3/4-inch thick by machine methods in May 1967 and was first skid tested in October 1969. At the time of the initial skid tests, the traffic lanes had been exposed to ten million vehicle axles while the passing lanes had been exposed to three million axles.

The results of the skid tests made on this rubberized trap rock mix are presented as a function of skid number versus time and skid number versus traffic volume in Figures 28 and 29. Initially, the mix had acceptable skid resistance, but as the number of axle passes increased, the skid resistance decreased to a marginal level. The passing lanes exhibited a consistently higher skid number which is due primarily to the lower number of axle applications in the passing lanes as compared to the traffic lanes.

During the November 1971 tests, a sharp drop in skid number was noted in the northbound lanes. Visual inspection revealed that reason for the low skid numbers was that asphalt had been spilled extensively over the surface, eliminating surface texture in the wheelpaths. The following winter and spring, vehicular traffic wore away the contamination, and by the following summer skid resistance of that surface had been restored to its former level.

This mix has maintained acceptable skid resistance in the passing lanes for over four years while accumulating over six million vehicle axles. The skid resistance in traffic lanes, however, dropped to the marginal level because the traffic lanes were exposed to the passage of over 20 million axles during the same four-year period, and if the mix were placed at a location where vehicular speeds are below 35 mph, then skid resistance should be acceptable even with the high traffic volume.

TABLE 22

TYPICAL GRADATION OF TRAP ROCK - LINCOLN

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
No. 4	100	100
No. 10	90 - 100	92.4
No. 40	50 - 80	52.2
No. 80	15 - 40	30.2
No. 200	5 - 10	7.5

TABLE 23

TYPICAL EXTRACTION TEST RESULT OF TRAP ROCK MIXTURE WITH R-504 RUBBER

Sieve Size	Percent Passing (By Weight) Specification Limits	Sample
1/2 inch	100	100
No. 4	100	99.4
No. 10	90 - 100	91.5
No. 40	50 - 80	44.5
No. 80	15 - 40	20.6
No. 200	5 - 10	4.9
Bitumen (AC 85 - 100)plus R-504 Rubber	6 - 10	8.0

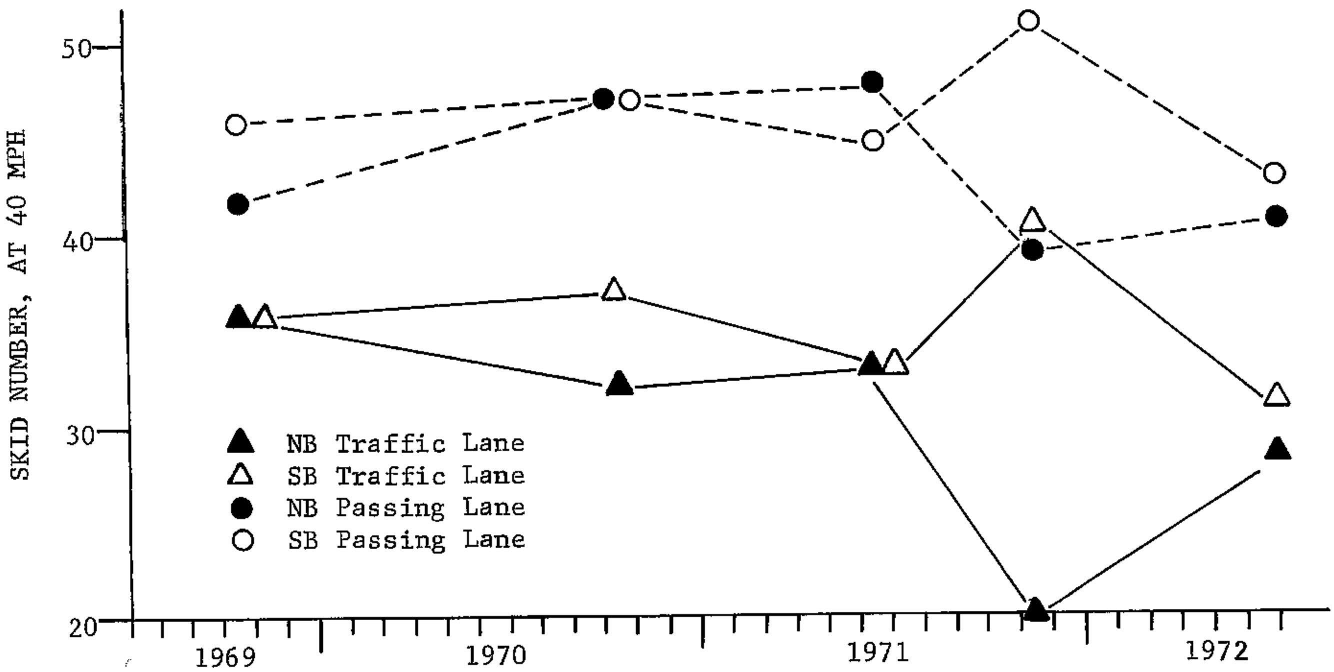


Figure 28. Graph of skid number as a function of time for the rubberized trap rock mix on US 66 at Lincoln.

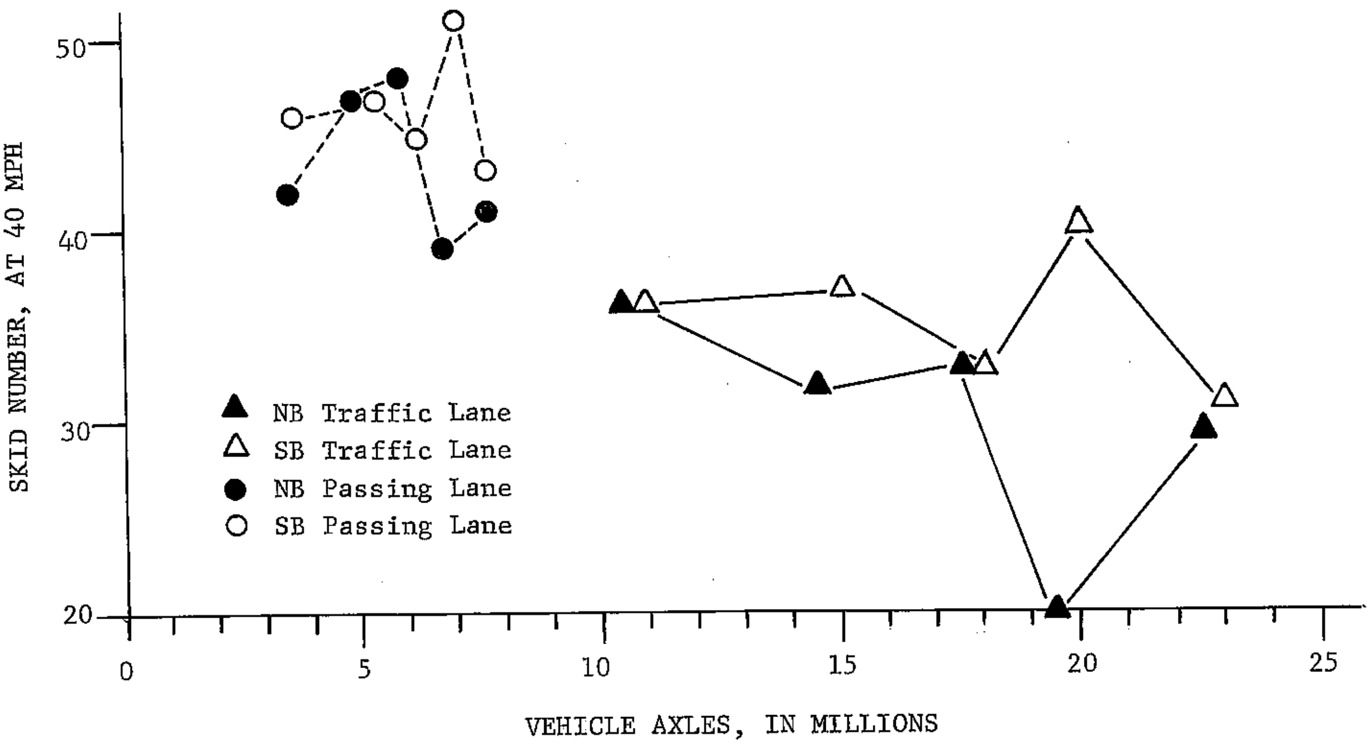


Figure 29. Graph showing effect of accumulated axles on rubberized trap rock mix on US 66 at Lincoln.

Gripstop - Cicero at Ill. 83

A modified Kentucky rock-asphalt mix called Gripstop was placed on Route Illinois 50 (Cicero Avenue) at Route Illinois 83 in Cook County. This installation covers all four lanes of the north leg of the intersection and extends approximately 500 feet north of the intersection. With this arrangement, the southbound lanes of the test site carry traffic approaching the signalized intersection, whereas the northbound lanes carry the traffic which is leaving the intersection. The four-lane undivided pavement has an annual ADT of 21,000 vehicles.

A material impregnated sandstone used in preparing Gripstop was mined in Kentucky. Prior to shipping the material to Illinois, the producer crushed and processed it to provide a more uniform asphalt content. The sandstone contained about 4 1/2 percent natural bitumen and was enriched by the contractor with an additional 5 1/2 percent asphalt. Test results of an extraction of the mix are given in Table 24.

The mix was laid by conventional methods to a compacted thickness of 1 inch. This experimental anti-skid mix was placed in October of 1968, and the first skid tests were made in November of 1969. During the year that elapsed between the date the pavement was opened to traffic and the date it was skid tested, each of the traffic lanes had been exposed to over four million vehicle axles and each of the passing lanes had been exposed to over three million axles.

The results of the skid tests made on this sand asphalt mix are shown as skid numbers versus the time of year in Figure 30 and as skid numbers versus the number of vehicle axles in Figure 31. Overall, the Gripstop retained satisfactory skid resistance for over ten million axle passages in 2 1/2 years. Both traffic lanes exhibited similar behavior in which the skid resistance showed a

TABLE 24

TYPICAL EXTRACTION TEST RESULTS OF GRIPSTOP MIXTURE - CICERTO AT I11. 83

Sieve Size	Percent Passing Sample
1/2 inch	100
No. 4	98.4
No. 10	92.8
No. 40	77.9
No. 80	18.9
No. 200	6.1
Bitumen (85-100)	8.5

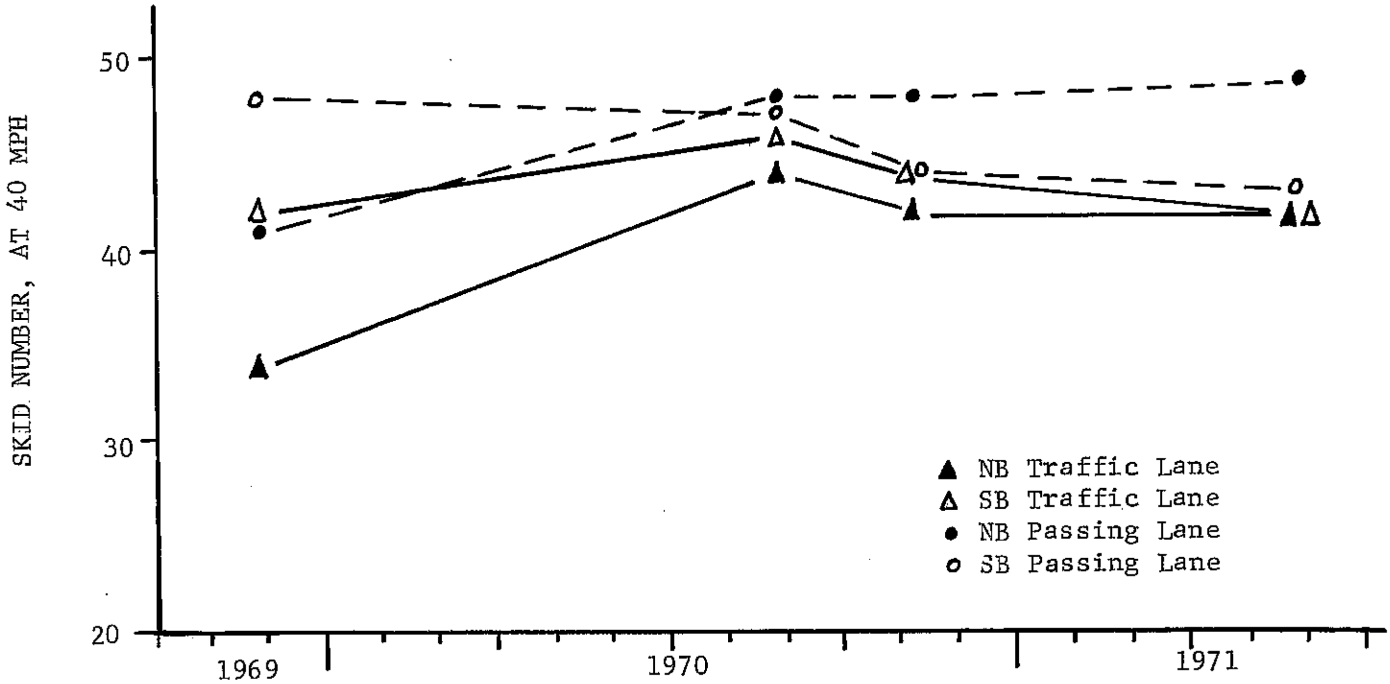


Figure 30. Graph of skid number versus time for Gripstop on Cicero Ave. at Ill 83.

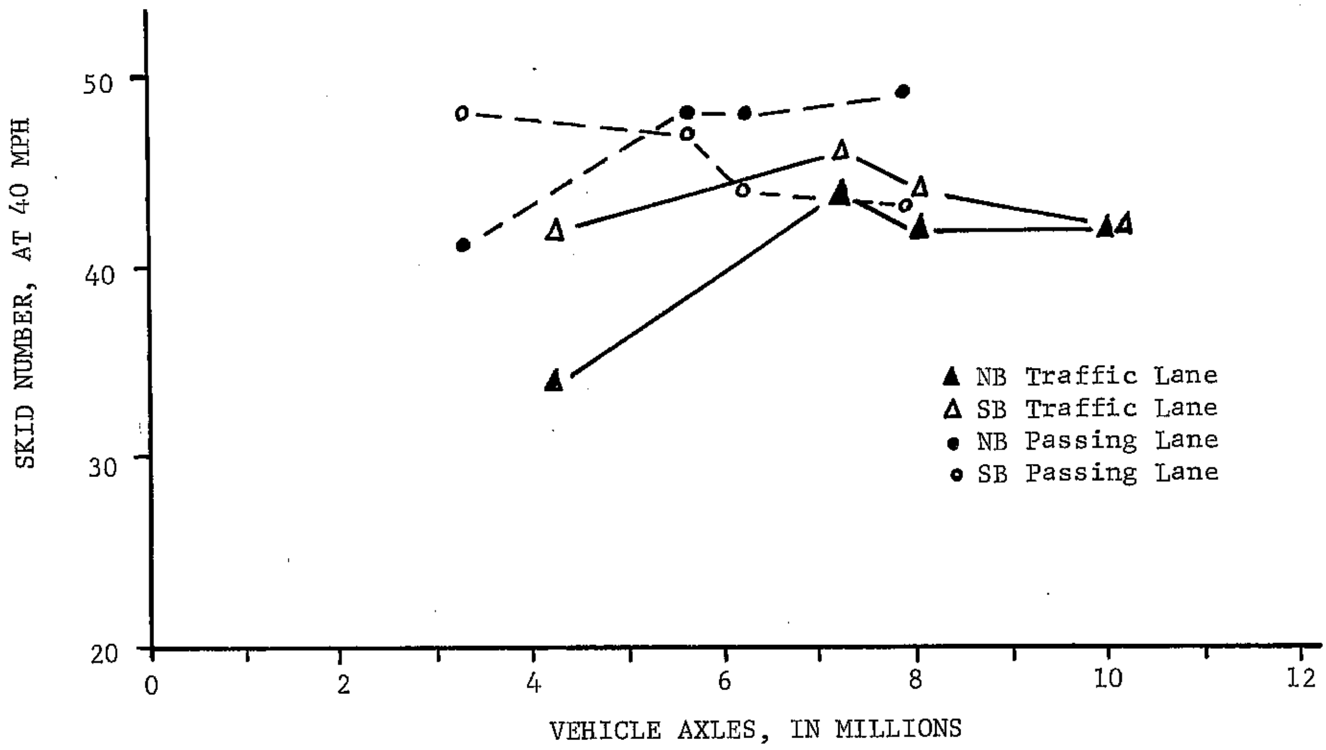


Figure 31. Graph of skid number versus accumulated axles for Gripstop on Cicero Ave. at Ill 83.

slight increase before leveling off at a skid number of 42. The passing lanes started somewhat higher than the traffic lanes, and although the southbound passing lane eventually reached the skid resistance level of the traffic lanes, the norhtbound passing lane continued to show an increase in skid resistance.

This mix shows little tendency to polish as the skid number is still above 40 after over ten million axle passes in the traffic lanes. Research work in studies of Kentucky rock-asphalt in other states also indicates the resistance of this mix to polishing.

No consistent nor significant difference in skid resistance is evident between those lanes which serve as an approach to the intersection and those which are exposed to traffic leaving the intersection. The braking action of the vehicles approaching the intersection apparently does not increase the rate at which the aggregates polish in this mix. While this mixture has maintained an adequate skid resistant surface tnroughout the test period, the wear characteristics of the mix have been less than desirable for the traffic at this location. By November 1972, three years after placement, vehicular traffic had worn through the surface in the wheelpaths of the traffic lanes. The results of this single installation indicate that the use of Gripstop as a skid corrective measure is limited to low traffic volume locations.

Wet-Bottom Boiler Slag

Experimental bituminous concrete mixtures with wet-bottom boiler slag as the principal aggregate were placed at two locations in the State to improve skid resistance. The first overlay was placed on the roadway across Spaulding Dam in Springfield, and the other was placed at the intersection of US 66 and Ill. 47 near Dwight. Both of these mixtures conformed to the Standard Specifications for Road and Bridge Construction except that wet-bottom boiler slag was specified as the principal aggregate. The composition of these mixtures was very similar as can be seen in Table 25.

The slag mix in Springfield was placed in May 1966 on a two-lane pavement carrying an ADT of 5,600 vehicles. Passenger cars account for 95 percent of the daily traffic at this location. At Dwight, the slag mix was placed on all four approaches to the intersection in May 1971. At this signalized intersection, US 66 is a four-lane divided highway with an ADT of 14,200 vehicles and Ill. 47 is a two-lane highway with an ADT of 4,800 vehicles.

Skid tests were made on the Spaulding Dam mix in June 1971 and on the Dwight mix in July 1972. The results of these tests are tabulated in Table 26.

A comparison of the skid numbers for these two mixtures shows how vehicular traffic at a specific site can influence skid resistance. The slag mix on the Spaulding Dam pavement has an acceptable skid number even though the surface was more than five years old when tested. The same type of slag mix placed near Dwight has marginal skid numbers and the surface was only one year old when tested. This marked difference in skid resistance may be attributed to the amount and difference in the composition of traffic volume. As mentioned previously, the Spaulding Dam carries less than five percent truck traffic, whereas the Dwight traffic (on US 66) consists of 25 percent trucks. Moreover, contamination caused by more traffic at Dwight leaves less chance for weathering to cleanse the surface. In contrast, the lighter traffic at the Spaulding Dam location allows weathering to play a larger role in maintaining satisfactory skid resistance.

TABLE 25

TYPICAL EXTRACTION TEST RESULTS OF WET-BOTTOM BOILER SLAG MIXTURE

Sieve Size	Percent Passing (By Weight) Spaulding Dam	Dwight
1/2 inch	100.0	100.0
3/8 inch		100.0
No. 4	99.4	96.5
No. 10	80.2	81.6
No. 40	36.6	32.6
No. 80	12.3	16.0
No. 200	5.4	4.9
Bitumen	6.9	6.4

TABLE 26

RESULTS OF SKID TESTS - WET-BOTTOM BOILER SLAG MIXTURE

Location	Date of Test	Direction	Lane	Number of Axles (Millions)	Skid Number 40 MPH
Spaulding Dam	6-71	EB	Traffic	9.3	40
		WB	Traffic	9.3	40
Dwight (US 66)	7-72	EB	Traffic	6.4	31
		EB	Passing	1.7	43
		WB	Traffic	6.4	30
		WB	Passing	1.7	37
Dwight (Ill.47)	7-72	NB	Traffic	2.4	35
		SB	Traffic	2.4	31

DISCUSSION

Surface roughness, commonly referred to as texture, according to Kummer and Meyer plays an important role in providing adequate skid resistance of any wet surface. 3/ Obviously, coarse-textured or open-graded surfaces allow for better drainage between the tire and the wet surface than do fine-textured surfaces. When vehicle speeds are less than 35 mph, both fine- and coarse-textured surfaces are adequate, but when vehicle speeds exceed 35 mph, coarse-textured and open-graded surfaces maintain better contact between the tire and the pavement than do fine-textured surfaces. As pavement contact is lost, the vehicle tends to hydroplane, particularly as its speed approaches and exceeds 50 mph.

Because texture plays such an important role in skidding, all experimental bituminous mixtures presented here first were divided into either sand-asphalt or surface and binder course categories and then were ranked according to their adjective rating which was previously described. These comparisons, which are presented in Table 27, are based solely on skid resistance; no attempt has been made to compare their relative merits based on structural behavior or construction costs. A quick glance at Table 27 reveals that hard and gritty aggregates generally prevail over soft polishing aggregates in providing adequate skid resistance. This trend reinforces what Kummer and Meyer have reported.

When several experimental mixtures are placed at one site, they are easy to compare, but when an experimental mix placed at one site is compared with another experimental mix placed at a different site, they are more difficult to compare because of differences in traffic volumes, in climate, and in pavement geometry and alignment which all affect skid resistance in varying degrees. For example, the skid number of a rural highway which has an Average Daily Traffic (ADT) of

TABLE 27

SUMMARY OF SKID TEST ADJECTIVE RATINGS FOR EXPERIMENTAL BITUMINOUS MIXTURES

Type Mixture	Type Location	No. of Accumulated Axles x 10^6	Adjective Rating
<u>Sand Asphalt Mixtures</u>			
Gripstop	Urban intersection	10	Acceptable
Tapisable - Champaign	Urban Street	6	Acceptable
Slag Sand - Troy	Rural highway	2	Acceptable
Tapisable - Aurora	Urban Street	1	Acceptable
Natural Sand - Urbana	Urban Street	0.5	Acceptable
Trap Rock / Rubber	Rural intersection	20	Marginal
Trap Rock	Urban Street	10	Marginal
Stone Sand - 25th Ave.	Urban Street	10	Marginal
Stone Sand / Rubber-Cermak	Urban Street	10	Marginal
Stone Sand - Odell	Rural intersection	5	Marginal
Stone Sand - Troy	Rural highway	2	Marginal
Natural Sand-Effingham	Rural highway	2	Marginal
Wet-Bottom Boilder Slag	Urban Street & Rural intersection	6	Marginal
<u>Bituminous Concrete Binder and Surface Course</u>			
Synopal, 50 percent-Pontiac	Rural highway	26	Acceptable
Slag, Surface course mix	Rural highway	2	Acceptable
Slag-Limestone surface course mix	Rural highway	2	Acceptable
Slag, binder course mix	Rural highway	2	Acceptable
Slag -Limestone, binder course mix	Rural highway	2	Acceptable
Synopal, 50 percent - Dan Ryan	Urban Expressway	28	Marginal
Synopal, 25 percent-Pontiac	Rural highway	26	Marginal
Crushed Gravel	Urban intersection	15	Marginal
Ramflex, crushed gravel / rubber	Urban Street	7	Marginal
Class I / asbestos	Urban expressway	28	Unacceptable
Class I / stone sand	Urban expressway	28	Unacceptable

<u>Rating</u>	<u>Skid Number</u>
Acceptable	Above 36
Marginal	30 - 36
Unacceptable	Below 30

1,000 may be higher and may fluctuate more because of weathering and seasonal changes than the same surface placed on an urban expressway which carries an ADT of 200,000 and whose surface is rapidly worn and continuously contaminated. Likewise, curves and intersections generally wear faster than the open highway because drivers turn, decelerate, and accelerate their vehicles at these locations instead of driving at a constant speed as they do along an open highway. The more all of these factors are alike at different test sites, the easier it is to compare differences in experimental mixes.

By holding the number of accumulated axle passes and the type of location for test sites similar, reasonably good comparisons between or among experimental mixtures can be expected to show how aggregate type or gradation or additives affect skid resistance. In this discussion, comparisons are made among natural and synthetic aggregates and aggregate blends. Also, the effect of changing aggregate gradation is examined by observing changes in skid number and the effect of adding rubber or asbestos to a mix is presented.

<u>Sand Asphalt Mixes</u>

A comparison among limestone stone sand mixes, which are at four different sites in the State, indicates little difference in reported skid resistance. Although the surfaces had different initial skid numbers, ranging from the upper 50's to the lower 30's, they all have reached a marginal skid number level (30 to 36) after accumulating from two to three million axle passes. The gradations of aggregates at the 25th Avenue and the Cermak Road sites are similar but vary slightly from the Troy and Odell sites. Although the mix at Cermak Road contains a rubber additive, no significant influence of the rubber additive was reflected in skid numbers obtained recently from these surfaces.

Likewise, adding a rubber compound to the trap rock mix did not affect the skid resistance of that mix significantly. This can be seen by comparing the mix (without rubber) at Decatur to the mix (with rubber) at Lincoln, as both mixes have marginal skid resistance after accumulating ten million axle passes.

Trap rock mixes, unlike stone sand (limestone) mixes, generally have shown little loss in skid resistance because of wear and polishing, but tests suggest that their skid resistance fluctuates more seasonally than stone sand mixes.

Skid test results suggest that sand asphalt mixes containing natural sands usually have higher skid numbers than mixes containing manufactured sands. Referring again to Table 26, two exceptions are apparent; one is the sand mix at Effingham and the other is the slag sand at Troy. The Effingham mix which has a marginal skid resistance contained a fine, rounded natural sand which could be placed easily as a one-half inch surface but resulted in a tighter, smoother-textured surface. The reasons that slag sand gave such a high skid number are that the slag sand is coarser (approximately 40 percent was retained on the No. 10 sieve as compared to a high of 16 percent for other sand mixes), and that slag has more microroughness than either stone sand or trap rock.

Even though each surface is exposed to a different amount and rate of wear, the influence of aggregate type becomes evident as axle passes accumulate. Initially, Gripstop, Tapisable, Slag, natural sand, trap rock, and stone sand all had acceptable skid resistance, but after two million axle applications, trap rock and stone sand dropped to a marginal level. As the number of axle passes reached five million, the skid resistance of Gripstop and Tapisable continued to drop but they still maintained an adequate level of skid resistance, while trap rock and stone sand leveled off and continued to maintain a marginal level of skid resistance. Skid tests measured on Gripstop, stone sand and trap rock after ten million axle passes suggest that the earlier trends established after five million applications have continued, and that other mixes which have not yet reached ten million applications can be expected to behave similarly.

Surface and Binder Course Mixes

For surface course mixes, the Synopal mix at Pontiac was compared with the Synopal mix at Chicago. Although both mixes contained 50 percent (by volume) Synopal coarse aggregate, have similar aggregate gradations, and have been exposed to at last 26 million axle passes, the surface at Pontiac consistently has had a skid resistance up to four skid numbers higher than the Chicago site.

The lower skid number at Chicago possibly is related, in part, to surface contamination from passing vehicles and to the larger number of heavy trucks using the expressway. With higher expressway traffic volumes at the Chicago site, oil and fuel dripping from passing vehicles accumulated so rapidly that very little benefit appeared to be derived from the cleansing action of precipitation. Moreover, for approximately the same number of axle passes, the Pontiac site was exposed to weathering 35 months as compared to 21 months for the Chicago site. This longer exposure to weathering elements, in addition to lower traffic volumes, may be another factor which has contributed to the higher skid numbers at the Pontiac site.

Incidentally, skid tests made at Meigs Field in Chicago where an airport runway was resurfaced with bituminous concrete containing 50 percent Synopal aggregate, top size 3/4 inch instead of 3/8 inch, gave an average skid number in the middle 60's, which is at least 20 skid numbers higher than those obtained at either the Chicago or at the Pontiac sites when they were new. Using larger Synopal aggregate in a bituminous mixture increases not only macroroughness, but also microroughness of that surface which, in turn, raises its skid resistance. The benefit of improving both macroroughness and microtexture is quite evident from this comparison.

In the same sense, the air-cooled slag mixes at Troy, all of which are well within the adequate skid resistance range, merit discussion even though they have been exposed to only two million axle applications. The vesicular nature of air-cooled slag, which gives a frictional quality to the aggregate, enhances skid resistance. This is apparent when comparing a binder course slag mix to a binder course limestone mix (Figure 8). Because most of the surface represents exposed coarse aggregate, the skid resistance measured on that surface reflects mostly the frictional properties of the exposed aggregate. The skid resistance of the slag surface was 15 skid numbers higher than the limestone surface, and clearly indicates the benefit of an aggregate having microroughness.

Furthermore, the Troy experiment suggests that there may be an optimum coarse aggregate gradation that gives a higher skid number for dense-graded bituminous mixtures, at least for speeds up to 50 mph. This relationship was seen previously in Figure 6 where sand mixes have the lower skid numbers, the surface course mixes have the higher skid numbers, and the binder course mixes have intermediate skid numbers. Within the limits of these tests, the aggregate gradation used in Class I bituminous concrete surfaces appears to be near the optimum macroroughness for dense-graded bituminous concrete mixtures placed in Illinois.

As previously mentioned in the results of the Troy experiment, the skid resistance of the slag and the slag-limestone surface course mixes was nearly the same. The reason for this is believed to be related to aggregate gradation. As can be seen in Table 5, the slag mix is finer with less material retained above the No. 10 sieve than the other two mixes. The specifications for slag aggregate called for a gradation from 3/8 inch to dust. If this specification were changed to require a gradation from 5/8 inch to dust, the amount and distribution of aggregate retained above the No. 10 sieve should be more nearly like the other two mixes. Correspondingly, a high skid resistance would be expected.

Crushed gravel was substituted for limestone as coarse aggregate in a Class I surface mix at Danville. This surface has been in service for at least three years and has carried ten million axle applications since it was placed. This crushed gravel mix has shown little, if any, loss in skid resistance since it was placed. In fact, the little variation that has occurred came from seasonal fluctuations.

When coarse aggregates like Synopal or slag are blended with limestone in a bituminous mixture, they raise the skid resistance (macroroughness) of the surface above a surface containing only limestone. Correspondingly, blending crushed gravel with limestone in a Class I surface mixture shows promise as a means of increasing its macroroughness and, at the same time, raising its skid resistance. Skid numbers obtained from a crushed gravel-limestone bituminous mix placed on a LaSalle County highway, where traffic volumes equal 500 vehicles per day and weathering is apparent, range from 55 to 65. However, if this surface were exposed to an average daily traffic of 10,000, its skid resistance would be expected to drop but still remain within an acceptable skid resistance range.

Finally, this study has proven that more can be learned about skid-resistant surfaces when several experimental bituminous mixtures are placed at one site than when a single bituminous mixture is placed at several different sites. A comparison of the behavior of any bituminous surface is greatly simplified and more meaningful if all of the experimental mixtures are placed at one geographical location. With only one location, many important variables that affect skid resistance, such as traffic volume and composition, time, weather, and contamination, are the same; thus, resulting differences in skid resistance can be traced directly to a difference in experimental mixes or to a difference in construction methods. Conversely, any comparison of experimental mixes at various locations inevitably leads to difficulties in sorting out and in weighing the influence of each factor on the skid resistance of the mixes involved.

RECOMMENDATIONS

After two to four years of field testing, this phase of the research has provided useful information that should be considered in designing bituminous concrete mixtures for improved skid-resistant qualities. The research work has been concerned primarily with dense-graded bituminous concrete mixtures and sand-asphalt mixtures, and with certain types of aggregates in these mixtures. There are other mixtures and other types of aggregates that also can provide very satisfactory skid-resistant surfaces. Recent work with open-graded plant mixed seals shows these mixes to have excellent surface drainage characteristics and good skid-resistant qualities.

Within the limits of the work covered under this study, however, the following recommendations are offered for use in selecting skid-resistant mixtures:

(1) Bituminous concrete surface courses, Class I, although considered a fine-textured surface, are recommended over sand-asphalt mixtures for open highways, particularly where vehicular speeds exceed 45 mph.

(2) Hard angular aggregates that have excellent microroughness (gritty surfaces) should be used in skid-resistant mixes. Rounded aggregates and aggregates susceptible to polishing should be avoided.

(3) Sand-asphalt mixes may be considered for improving skid resistance in urban areas and other sites where vehicular speeds do not exceed 45 mph. Hard, angular, clean sands that are not susceptible to polishing should be used. Tests indicate that Tapisable, Gripstop, air-cooled blast furnace slag sand and natural angular sands produce mixtures that provide satisfactory skid resistance. The wear characteristics of Gripstop indicate that it should be limited in use to locations with reasonably low traffic volumes. Sand-asphalt mixes composed of 100 percent limestone sand, which is susceptible to polishing, should not be used.

(4) In lieu of complete replacement of soft, polishing aggregates in bituminous mixtures to produce good skid-resistant characteristics, satisfactory skid-resistant mixtures can be produced by blending hard, polish-resistant aggregates with soft aggregates in approximately equal proportions.

(5) Rubber additives did not improve skid resistance, but they may be used to modify the physical properties of the asphalt binder without sacrificing skid-resistant qualities of the mixture.

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